도시계획학 석사학위 논문

Estimating price elasticity of energy inputs across manufacturing sectors in Korea using the generalized logit model

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일반 로짓모델을 이용한 국내 제조업 에너지원 가격탄력성 추정

2013년 8월

서울대학교 환경대학원
환경계획학과
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이 논문을 도시계획학 석사학위 논문으로 제출함

2013 년 8 월

서울대학교 환경대학원

환경계획학과

신 희 영

신희영의 도시계획학 석사 학위논문을 인준함

2013 년 8 월

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Abstract

Estimating price elasticity of energy inputs across manufacturing sectors in Korea using the generalized logit model

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This paper examines the own- and cross-price elasticities of the factor inputs of industrial production with a focus on energy. Applying the generalized logit model, electricity, oil, gas, coal, labor, and capital are included as factor inputs. First, the model is applied to total manufacturing and then to the three sub-sectors within manufacturing: petrochemical, nonmetal, and iron & steel. In the process, different price-weights in the generalized logit model are explored to find which functional form provides a best fit of the empirical data. The calculated elasticities show own-price elasticities as well as the cross-price elasticities to be inelastic. Depending on model specification, the comparative magnitude of the elasticities differ, which leads to the conclusion that while the calculated elasticities are a good indicator of past trend, it is a rough estimate in terms of predicting future change in demand due to price changes. Policy implications should be limited to conclusions that can be reached from all specifications of the generalized logit model, and any future study should also employ a grid search over the different price-weights in the generalized logit model.

◆ Key words : price elasticity, generalized logit model, production function, energy factor input, manufacturing sector

◆ Student number : 2011-23928

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I. Introduction

The importance of reducing CO_2 emissions from the manufacturing sector has been discussed extensively in climate change mitigation policies. The majority of CO_2 emissions in the manufacturing sector comes from the use of energy, and towards that end some policy mechanisms aiming to put a price on greenhouse gas emissions have been proposed and implemented. One integral part of designing such a policy is knowing the price elasticity of energy inputs. Theoretically, once a reduction target is set, price elasticity can be used to predict how much the price adjustments should be before actual implementation. Many econometric models have been applied to forecast market behavior following a price adjustment. The determination of price elasticities is important especially in top-down models dealing with energy demand assuming economic factors as key drivers of changes in consumption.

Different models may be applied to calculate price elasticity. Past studies comparing these models show the value and accuracy of the calculated price elasticities differ by model. Some models do not yield results at all, while in some cases the derived results are in violation of economic logic (eg. positive own-price elasticities). Once a flexible functional form is applied, it is checked to see if it adheres to economic theory. One of the most common forms used is the translog model, but in comparative studies the generalized logit model has performed better when modeling factor inputs that account for only a small percentage of total cost. However, previous studies on the elasticity of energy inputs in Korea have applied the translog model and not the generalized logit. Hence this paper uses the generalized logit model to analyze the price elasticity of energy inputs across Korea's manufacturing industry.

Forecasting and managing the manufacturing sector's energy consumption is part of Korea's energy planning. Policy makers need to know how these industries react to changes in energy price, first of all because energy prices are externally determined by the global market, and also for reference in policy designs attempting to place a price on carbon. As such, this paper analyzes both the manufacturing sector as a whole and in parts. One reason for conducting the same analysis on the aggregate manufacturing industry and its subsectors is to determine what effect aggregation has on the results. Second, the three subsectors which are the subject of this study account for over half of energy consumption in the manufacturing sector, and their price elasticities has useful policy implications.

The paper is organized as follows: in section two, past literature concerning energy consumption modeling in the industrial sector is reviewed, leading up to the generalized logit model used in this paper. Empirical studies on the Korean industrial sector are covered next. Then, a review of literature concerning how to tabulate the quantity and price of capital input is conducted, as the method employed greatly influences the final outcome of the analysis. In section three, the theoretical aspects of the generalized logit model are explained, and an explanation on the data used for empirical analysis is given. In section four, the results of the econometric modeling is presented together with a discussion. Concluding remarks are given in the last section.

II. Survey of literature

1. Studies on modeling industrial energy demand

Modeling involves identifying appropriate functional forms to reflect empirical data based on economic theory. Diverse methodologies can be applied, such as decomposition of energy trends, econometric methods, 'top-down' models, 'bottom-up' or engineering models, and industry specific micro-economic analysis (Greening, 2007). The model chosen differs depending on the question posed by each study. The purpose of this paper is to identify the own- and cross- price elasticities of energy factor inputs for the manufacturing industry as a whole, and for three sub-sectors of the manufacturing industry, based on economic theory. While incorporating the best of all modeling methodologies and thereby making up for the shortcomings of each would be ideal, this paper focuses on the top-down econometric model. The econometric top-down approach was selected to review historic trends in energy consumption.

Extensive study has been conducted on the production function and its factor inputs using econometric methods. Energy input as a factor input had traditionally been overlooked compared to other factor inputs such as capital, labor, and materials. As one of the first studies dealing with energy use in the industrial sector, Berndt and Wood (1975) characterized the structure of technology in the United States manufacturing by providing evidence on the possibilities of substitution between energy and non-energy inputs using the KLEM (capital, labor, energy, and material inputs) model, exploring the substitution effects and complementarity between energy and non-energy inputs for United States manufacturing between 1947-1971. The translog functional form was used. Energy own-price elasticity was found to be about -0.5, energy and labor are found to be substitutes, while energy and capital complements.

Similarly, Fuss (1975) studied the case for Canada, incorporating six energy inputs using a two-stage optimization model. The weak seperability assumption between capital, labor, energy, and material inputs were imposed on the first stage, while homothetic weak seperability assumption was imposed on the second stage to determine energy inputs. As with Berndt and Wood (1975), the translog functional form was employed for empirical analysis. Pindyck (1979), using the same functional form and modeling approach, analyzed pooled intercountry data from 1959 to 1973. The model represents producers who first choose fuel sources to minimize energy costs, and then minimize total costs by choosing optimal levels of capital, labor, and energy inputs. The energy input is an instrumental variable, first computed from the interfuel substitution model and then used for interfactor substitution.

The translog model is widely used to this day. However, while the translog models are easy to apply, they are sensitive to situations in which some expenditure shares are close to zero (Weng and Mount, 1997). This necessitates the use of a two-step approach. To better model energy inputs, an alternative functional form, the linear logit, was posed by Considine and Mount (1984). The linear logit was conventionally used in discrete choice problems, and by seeing the choice between production factors as the price share, the linear logit can be applied to the production process. In a comparative study using both the logit and translog function to model the U.S. industrial sector from 1970 to 1985 (Considine, 1989), the linear logit model was shown to adhere to the properties of the production function assumed by economic theory, more so than the translog. Jones (1995) showed similar results applying a dynamic logit and translog approach to the same data.

The generalized logit model is difficult to estimate, but the derivation of elasticities from the estimated parameters is relatively simple and easy to interpret. Studies on modeling the production function in the industrial sector are summarized in Table 1; based on this review, the generalized logit model was selected as the most appropriate functional form for modeling energy demand in the Korean manufacturing sector. The functional form is explained in section III.

Table 1. Literature review on econometric modeling of production functions

Paper	Modeling: Factor inputs	Modeling: Functional form	Importance	Data used	Results
Berndt and Wood (1975)	·Capital, labor, energy, and material inputs	·Translog	·First to incorporate energy as a factor input	·Yearly data for US manufacturing; 1947-1971	·Energy own price elasticity -0.5 ·Energy and labor substitutes ·Energy and capital complements
Fuss (1975)	·First stage: capital, labor, energy, and material inputs ·Second stage: coal, liquid petroleum gas, fuel oil, natural gas, electricity, and motor gasoline	·Two-stage optimization using translog	·Forging of an explicit link between the energy sub-model and the model explaining demand for the aggregate inputs	·Time series cross-section data set; Quebec, Ontario, the Prairies and British Columbia and the Yukon; 1961-1971	·Negative own-price elasticity for all individual energy inputs ·Energy own price elasticity -0.486 ·Energy and labor substitutes ·Energy and capital compliments ·Energy and material input compliments
Pindyck (1979)	·First stage: capital, labor, and energy ·Second stage: coal, oil, gas, and electricity	·Two-stage optimization using translog	·International comparison of 10 countries show general trends in energy use worldwide ·Results are similar across countries, showing applicability of the functional form, while those that do not adhere to general trends can be picked out	·Time series cross-section (10 countries) data set; 1959-1973 for energy inputs; 1963-1973 for total cost function	·Negative own-price elasticity for all individual energy inputs ·Electricity most inelastic out of all energy inputs ·Energy and labor substitutes in all countries ·Energy and capital compliments in all countries
Considine and Mount (1984)	·Electricity, natural gas, oil, and gasoline and diesel fuel	·Linear logit	·Applied the linear logit model as the functional form ·The static and dynamic model was proposed to estimate short- and long-term elasticity	·Time series cross-section dataset; 14 Northeastern and North Central states (US); 1964-1977	·Negative own-price elasticity for all individual energy inputs ·Energy inputs are substitutes to other energy inputs except for oil and gasoline and diesel fuel

Table 1 (continued). Literature review on econometric modeling of production functions

Paper	Modeling		Importance	Data used	Results
	Factor inputs	Functional form			
Considine (1989)	·Labor, energy, capital, materials	·Translog and the linear logit	·Compares the translog and the linear logit model ·While both violate concavity restrictions, the logit model has fewer violations ·Translog model shows energy own-price elasticity to be positive; linear logit shows it to be negative	·Time series dataset; US manufacturing; 1958-1981	·Determines how the two models fit the dataset, with analysis on concavity restrictions showing the linear logit adhering better to the theoretical restrictions ·the dynamic form is shown to yield a better fit compared to the static form
Considine (1990)	·Capital, labor, energy, material inputs, and output yield	·Extended linear logit	·Extends the linear logit by using an iterative procedure to impose symmetry on all predicted cost shares ·Recursive estimation strategy is proposed in which predicted shares from the logit equations are used as instruments in a log quadratic cost function	·Time series dataset; US manufacturing; 1947-1971	·The symmetric logic model used has a constant but unequal elasticities of substitution, which can be evaluated at the predicted shares
Jones (1995)	·Coal, oil, electricity, and natural gas	·Dynamic translog and linear logit	·Compares the dynamic linear logit model with global symmetry imposed with the dynamic translog model	·Time series dataset; US industrial fuel consumption; 1960-1992	·Reaches similar conclusions to Considine (1989) but with a larger and updated dataset

2. Studies on Korean industrial energy demand

Several studies have been conducted on the price elasticity of energy inputs in Korea's manufacturing industry. Most studies apply the two-stage translog model when examining individual energy inputs. Based on Considine (1990) and Jones (1995), the dynamic logit model is applied to the Korean manufacturing sector in this study. Also, previous studies examine Korea's industrial sector as a whole. Only two studies, Lee (2001) and Kim (2007) examines the subsectors within manufacturing, and they both apply the translog modeling approach. Hence this paper differentiates itself mainly in three ways: 1) use of the general logit model; 2) examining the manufacturing sector as a whole and three of its subsectors (which constitute over half of total energy demand); 3) using datasets for 1990-2010, the most recent data available.

To the author's knowledge, there are no previous studies employing the general logit model in Korea to model the production process. The linear logit model has been applied by Park and Na(2003) and Park (2006) to the manufacturing sector. Park and Na(2003) examined interfuel substitution in the industrial sector using both the static and dynamic linear logit models, using data for the period between 1981-2001. The static logit model and the dynamic logit model were applied in three versions: first, the basic model; second, with variables allowing for time trend reflecting autonomous technology advance for each fuel type; third, a non-homothetic model, adding a total yield variable to the second model, relaxing the assumption that energy inputs are independent from total production. While a direct comparison with the results from this study would be interesting, Park and Na (2003) limits its scope to the examination of fuel inputs, i.e. other factors of production such as capital, labor, and material inputs are not considered. This may have been due to the fact that deducing the price, quantity, and cost values for inputs such as capital and labor are not as straightforward as energy. The uncertainty surrounding the exact measurement of capital and labor is at odds with the additional insight gained by including these factor inputs. In this study, capital and labor are included as factor inputs in the production function to provide a model of the production function in its entirety.

Also, by examining the behavior of the manufacturing industry and three of its subsectors, the resulting price elasticity estimates can be compared. Knowing which sectors will be affected the most by price changes is a valuable insight for policy makers, as it becomes possible to target specific subsectors in policy design to minimize negative impacts and maximize effectiveness. Some studies have been conducted on the production function of the Korean industrial sector as a whole, but the only previous study analyzing the price elasticities of factors by subsector in a similar manner to this study was Kim (2007). Using a two stage translog model for yearly time series data from 1990 to 2004, 11 subsectors were analyzed separately. The analysis for total manufacturing shows results consistent with economic theory (i.e. negative own-price elasticities), but when broken down by sector, in some instances the own-price elasticities of energy inputs are positive. Negative own-price elasticities are reported in Kim and Labys (1988) and Park and Na (2003) as well. Kim and Labys speculate this could be the result of administrative control on energy prices and market imperfections, as during the period under study (1960-1980) the market was not fully liberalized and the government had strong influence on energy consumption by the industry.

Other studies on the Korean manufacturing sector provide a valuable basis to which the results from this paper can be compared. These are summarized in Table 2, together with notes on how this study differentiates itself from these previous studies. Recent studies cover aspects such as energy intensity and the effect of environmental regulations. This study serves to provide a more accurate model, and illuminate the changes that took place during 1990-2010.

Table 2. Literature review on econometric modeling of production functions in Korea

	Modeling		Data used	Results	Pertinence to this paper
	Factor inputs	Functional form			
Kim and Labys (1988)	·First stage: capital, labor, and energy ·Second stage: coal, oil, and electricity	·Two-stage translog cost function, following Pindyck (1979)	·Time series data by sub-sector; 9 manufacturing and 3 non-manufacturing subsectors; 1960-1980	·In Korea's case, industry is influenced by factors other than price, yielding own-price elasticity estimates inconsistent with economic theory; translog model does not provide a good economic explanation ·Results imply that changes in energy prices will not significantly reduce energy consumption in the energy intensive industries	·Period of study precede the span covered by this paper (1990-2010) ·Data regarding city gas usage was unavailable during the period under study; this paper includes city gas as an energy input ·The author notes that the translog model has not adequately explained energy substitution behavior in the industrial sector over a period of rapidly rising energy prices, and further dynamic specifications may help model performance
Lee (2001)	·Capital, labor, material input, energy, output quantity, and technological progress	·Two-stage translog cost function	·Time series data; manufacturing industry total and two sub-sectors	·The own-price elasticities of capital, labor, energy, and material input are found to be negative	·This paper examines energy input as individual inputs, i.e. coal, oil, city gas, and electricity, while Lee (2001) examines only as an aggregate, i.e. energy

Table 2 (continued). Literature review on econometric modeling of production functions in Korea

	Modeling		Data used	Results	Pertinence to this paper
	Factor inputs	Functional form			
Park (2003)	·Coal, oil, city gas, and electricity	·Linear logit model used by Considine and Mount (1984) ·Three variations were applied: 1) the basic model; 2) with variables allowing for time trend; 3) a non-homothetic model	·Time series dataset; Korean total industrial consumption; 1981-2001	·Explanatory power highest for the dynamic logit model with both time trend and total yield variables ·Long-term own-price elasticity for the dynamic logit model with both time trend and total yield as variables: city gas (-0.424), oil (-0.052), electricity (-0.024), and coal (-0.024)	·The modeling does not incorporate non-energy factors of production such as capital and labor. Energy constitutes a small portion of factor inputs in the production function, which is a large omission in modeling the production function. This paper incorporates capital and labor into the modeling.
Cho, Nam, and Pagán (2004)	·First stage: capital, labor, and energy ·Second stage: coal, oil, and electricity	·Two-stage translog cost function, following Pindyck (1979)	·Time series dataset, quarterly data for 1981:Q1-1997:Q4; Korean total industrial consumption	·Own-price elasticity for energy is found to be positive in the static model; contradicts economic theory ·Capital and energy are found to be substitutes, while labor and energy complements ·Dynamic model has negative own-price elasticity for energy	·Translog functional form is used in the analysis, necessitating the need for a two-stage process because the share of each energy input is close to zero in the production function. The two stage process models producers who first choose fuel sources to minimize energy costs, and then choose optimal levels of capital, labor, and energy inputs. ·This paper uses the generalized logit model which does not need to make such assumptions about producer behavior. ·Also, the positive own-price elasticities are attributed to administrative control on energy prices and market imperfections. The generalized logit model used in this paper should yield different results.

Table 2 (continued). Literature review on econometric modeling of production functions in Korea

	Modeling		Data used	Results	Pertinence to this paper
	Factor inputs	Functional form			
Kim (2007)	·Capital, labor, output yield, coal, oil, gas, electricity	·Two-stage translog cost function	·Time series data; 11 manufacturing subsectors; 1990-2004	·The interfuel and interfactor substitution possibilities are studied with an estimation of carbon tax based on the estimated price elasticities ·The own-price elasticity of energy as a factor input and the four energy inputs is positive in some cases.	·Kim (2007) uses the translog model; in this study, the generalized logit model is used ·The results from this translog model is compared to the results from a generalized logit model.
Kim and Heo (2010)	·Capital, labor, material input, fuel, and electricity	·Translog, with and without concavity restrictions imposed	·Time series data; Korean manufacturing industry; 1970-2005	·The study focuses on comparing whether the translog model with concavity restrictions performs better than the one without. The results with concavity restrictions yield economically more coherent results.	·In this study, the linear logit model is used instead of the translog, and the fuel component is broken down into oil, gas, and coal to focus on how each responds to change in price.

3. Studies on approximation of cost, quantity, and price of capital

Compared to other factor inputs, obtaining values of price, quantity, and cost of capital input is difficult. Obtaining the quantity and price (and total cost) of energy inputs is a straightforward matter, as they are generally homogenous goods that can be measured in physical quantities (e.g. energy inputs may be measured in units such as kgoe or kcal). The question concerning labor is also a difficult one; there are many different types of labor inputs that go into the production process. However, for labor, it is easier to make assumptions in regards to its homogeneity as an input.

Capital constitutes a large portion of factor input, and there is no doubt it is an integral part of the production function. The theory behind how to measure the quantity and price of capital input and in what units is a difficult subject, and there has been much discussion concerning this matter since the 1950s (Felipe and Fisher, 2003). Putting the theoretical problem aside, empirical data is limited, making theory inapplicable to the measurement of capital, and different studies have utilized different datasets, however lacking they may be. Hence empirical research has been limited, with no full agreement among economists on a single method of deducing data concerning capital.

The problem surrounding the aggregation of capital is dealt with in detail in the paper by Robinson (1953). The first question posed by Robinson is 'in what units is capital measured?' Other factor inputs such as energy or labor can be measured in their respective units, i.e. kgoe or kcal for energy and man-hour of work or persons employed for labor, but capital has no such unit of measurement; for the lack of a better option, capital is normally measured in units of currency. Next, the question of whether to value capital according to its future earning power or past cost arises. The problem of valuing capital according to cost of acquiring capital is inherent in the wording. Simply, value is not the same as cost. To find the value in terms of future earning power is still complicated; according to Robinson (1953), "When we know the future expected rate of output associated with a certain capital good, and expected future prices and costs, then, if we are given a rate of interest, we can value the capital good as a discounted stream of future profit which it will earn." All these things are not known to an economist, which makes accurate estimations of future earning power near impossible.

Other alternative units to measuring capital have been suggested as well. Again, quoting Robinson (1953), "when we consider what addition to productive resources a given amount of accumulation makes, we must measure capital in labour units, for the addition to the stock of productive equipment made by adding an increment of capital depends upon how much work is done in constructing it, not upon the cost, in terms of final product, of an hour's labour." But then, another question follows: How is it possible to value capital based on wage units, or in terms of a unit of standard labor, when labor is never expended in pure form, but is done with assistance of some form of capital? More still, measuring capital in terms of units of labor is realistically impossible, and therefore, economists are back to measuring capital in units of currency, as mentioned above.

Once one decides to measure capital in some way, well aware of the difficulties associated with it, the method suggested by Christensen and Jorgenson (1969) is often applied to determine cost and price of capital in analysis of production functions in the United States. However, this requires a detailed survey of industry to gather data needed for such calculations, and since such data is not available in Korea, a different method must be explored.[1] What follows is a review of past research conducted on the Korean manufacturing sector to estimate capital cost, quantity, and price, after which the most appropriate method was selected for this study.

In Lee (1997), cost of capital was calculated by subtracting employee income from net value added (excluding indirect tax) and dividing by producer price index to convert into real value. In this instance, capital was valued based on earning power and not cost of purchase. The data was from the

[1] The method suggested by Christensen and Jorgenson (1969) is as follows:

$$P_K = \left[\frac{1 - \omega \cdot z - \iota}{1 - \omega}\right] \cdot [hw_{t-1} \cdot r + hw_t \cdot d - (hw_t - hw_{t-1})]$$

where ω is corporate tax, $\mathrm{z} = \left(\frac{1}{\mathrm{r}\,\iota}\right)[1 - (1/(1+\mathrm{r}))\,\tau]$ where τ is the operation lifespan of the production facility. ι is the tax deduction rate for investment and hw is the Handy-Whitman capital price index, d is rate of depreciation, and r is profit ratio.

national account pertaining to GDP. The price of capital was found by dividing cost of capital by the year-end total tangible fixed assets in real terms. However, in Lee (2003), it is mentioned that this method of deriving price of capital is arbitrary, and the input distance function from Shephard (1970) is used to find price of capital instead.

In Nam (1990), the price of capital was construed as the cost of capital to the capitalist and the sum of average loan interest rate and depreciation rate was used as price of capital. The quantity of capital input was found by dividing capital cost by capital service price(P_{Kt}), which was derived by:

$$P_{Kt} = q_t \, (r_t + \delta_t)$$

where q_t is capital goods price, r_t is loan interest, and δ_t is the depreciation rate, all at time t. $q_t \cdot r_t$ represents opportunity cost for capital invested in production, while $q_t \cdot \delta_t$ stands for remuneration for depreciation. Capital goods price was derived by dividing the market price with constant price for total fixed investment, the data being available from the national account (BOK). Depreciation rate was derived from capital stock and yearly total investment. However, using this method is limited in the sense that the capitalist does not loan all his capital and that it could be self-sourced or from sources with lower interest rates.

In Kim and Huh (2010), the cost of capital was derived from domestic total value added and factor income, data available from the national account. The price of capital was calculated by dividing capital cost by capital input. Capital input figures were from the KIP Database, based on real capital stock. However, after 1997, this study was not conducted, and therefore from 1998 to 2010, perpetual inventory method is used to estimate capital input figures. The net capital in 1997 for 72 manufacturing sub-sectors is converted to 2000 real values using total fixed capital deflator, and then the total fixed capital accumulation between 1998 and 2010 are added with depreciation.

All the methods for tabulating cost, price, and quantity of capital are theoretically lacking, and the availability of data is limited as well. However, it was necessary to choose the best possible option out of the methods described above. In this study, price of capital was calculated using the method used in Floros, et al. (2005), as was used in Lee (1997), Kim (2007), and Kim and Heo (2010), which tabulates capital based on earning power. Capital stock figures were drawn from the KIP Database which provided a readymade set of data based on Pyo (2003).

III. Econometric Methodology and data

1. Econometric methodology: generalized logit model

The methodology employed in this paper is drawn from Considine and Mount (1984) and Weng and Mount (1997). Below is a summary of the theory and derivation of the final model. A more detailed explanation can be found in these papers.

From Considine and Mount (1984), representing N cost shares by a logistic function:

$$w_i = \frac{e^{f_i}}{\sum_{j=1}^{N} e^{f_j}} \quad for\ i = 1, 2, \ldots, N, \tag{1}$$

where $w_i = P_iQ_i/C$ is the cost share, P_i the price, and Q_i the quantity of the i^{th} input, and C is the total cost of N inputs. Then,

$$\ln\left(\frac{w_{it}}{w_{nt}}\right) = f_{it} - f_{nt} \quad for\ i = 1, 2, \ldots N-1, \tag{2}$$

and the expenditure system can be estimated in linear form once f_{it} is specified:

$$f_{it} = c_{i0} + \sum_{j=1}^{n} c_{ij} \ln(p_{jt}) + g_i \ln Y, \tag{3}$$

where c_{i0}, c_{ij} and g_i are parameters, p_{jt} price of input j at time t, and Y is the level of output.

The share elasticities can be written for any set of specific shares $(w^*_1, w^*_2, \ldots, w^*_N)$[2]:

$$H_{ik} = \frac{\partial \ln w_i}{\partial \ln P_k} = c_{ik} - \sum_{j=1}^{N} w_j^* c_{jk} \tag{4}$$

[2] $H_{ik} = \frac{\partial \ln w_i}{\partial \ln P_k} = \frac{\partial f_i}{\partial \ln P_k} - \frac{\sum_j^N e^{f_j}}{\partial \ln P_k} = \frac{\partial f_i}{\partial \ln P_k} - \sum_j^N w_j \left(\frac{\partial f_j}{\partial \ln P_k}\right) = c_{ik} - \sum_{j=1}^N w_j c_{jk}$

$$H_{iY} = \frac{\partial \ln w_i}{\partial \ln Y} = \ g_i - \ \sum_{j=1}^{N} w_j^* g_j.$$

In neoclassical economic theory, the demand functions can be derived for a set of price of inputs and level of output under the assumption of cost minimization. Defining the cost function as $C(P^*_1, P^*_2, \ldots, P^*_N, Y)$, where $P^*_1, P^*_2, \ldots, P^*_N$ are prices of N inputs and Y is output, then C is the minimum value of $\sum_{i=1}^{N} P_i Q_i$ that produces an amount greater or equal to Y. If the production function is regular, exhibits monotonicity and convexity, then the corresponding cost function is a non-decreasing, homogeneous, concave, and continuous function of the prices of inputs.

The conditional demand function derived here must exhibit the following properties according to economic theory, as listed by Considine and Mount (1984):

1) All levels of input must be non-negative

2) Each function must be zero-degree homogeneous in prices

3) The N x N matrix of elements, $\partial Q_i / \partial P_j$, must be symmetric and negative semi-definite, implying that own-price effects are negative and cross-price effects are symmetric.

The first condition is satisfied by the specification of the logit model. To impose restrictions meeting the second and third criteria, the expression for elasticity of demand is derived from the definition of the i^{th} cost share, Shephard's Lemma, and the definition of share elasticities H_{ik}:

$$E_{ii} = \frac{\partial Q_i}{\partial P_i}\frac{P_i}{Q_i} = \frac{\partial w_i}{\partial P_i}\frac{C}{P_i}\frac{P_i}{Q_i} + \frac{\partial C}{\partial P_i}\frac{w_i}{P_i}\frac{P_i}{Q_i} - \frac{w_i}{P_i}\frac{C}{P_i}\frac{P_i}{Q_i} = \ H_{ii} + \ w_i - 1 \qquad (5)$$

The cross-price elasticities are:

$$E_{ik} = \frac{\partial Q_i}{\partial P_k}\frac{P_k}{Q_i} = H_{ik} + \ w_k \quad for\ all\ k \ \neq i \qquad (6)$$

Adding (5) and (6), and applying the second restriction requiring each cost function to be zero-degree homogeneous in prices,

$$\sum_{j=1}^{N} E_{ij} = \sum_{j=1}^{N} H_{ij} = 0 \quad for\ all\ i. \qquad (7)$$

Symmetry of cross-price effects, from the third restriction, implies

$$(E_{ik} + w_k)w_i = (E_{ki} + w_i)w_k \quad or \quad E_{ik}w_i = E_{ki}w_k \quad for\ all\ k \neq i. \qquad (8)$$

Imposing both the homogeneity constraint (7) on the share elasticities derived in (4), by imposing the following N constraints both the homogeneity and symmetry constraints are satisfied:

$$\sum_{j=1}^{N} c_{ij} = d \quad for\ all\ i. \qquad (9)$$

Going back to (8) and substituting (4) and (6), the restriction

$$w_i^* c_{ij} = w_j^* c_{ji} \quad for\ all\ i \neq j\ , \qquad (10)$$

can be imposed based on the homogeneity and the symmetry constraint.

From Weng and Mount (1997), redefining the coefficient c_{ij},

$$c_{ij} \equiv \theta_{ij}\, \alpha_{ij},$$

and specifying θ_{ij} as:

$$\theta_{ij} = \frac{w_j}{(w_i + \delta)^{\gamma}\left(w_j + \delta\right)^{\gamma}}\ , \qquad (11)$$

then, from (10),

$$\alpha_{ij} = \alpha_{ji}.$$

And the regression equation for the generalized logit model is given as follows:

$$y_i = \alpha_{i0} + \sum_{j=1,j\neq i}^{n} \alpha_{ij}x_{ij} - \sum_{j=1}^{n-1} \alpha_{nj}x_{nj} + (g_i - g_N)\ln Y + e_i - e_N,$$

where

$$y_i = \log\left(\frac{w_i}{w_n}\right) \quad i = 1,2,\dots,n-1,$$

$$x_{ij} = \log\left(\frac{p_j}{p_i}\right) \quad for\ all\ j \neq i.$$

As seen in the functional form, explanatory variables other than Y may be added to the right hand side of the equation.

The Hicksian price elasticities for the generalized logit model are:

$$E_{ij} = \alpha_{ij}\theta_{ij} + w_j \quad for\ all\ i \neq j\ ,$$

$$E_{ii} = -\sum_{k=1,k\neq i}^{n} \alpha_{ik}\theta_{ik} + w_j$$

The value of δ and γ varies according to model specification. In Weng and Mount (1997), this cross price weight of θ_{ij} is employed to compare different variations of the generalized logit model. The model in Considine and Mount (1984) is equivalent to $\delta = 0$ and $\gamma = 0$; Dumagan and Mount (1993) applies $\delta = 0$ where $0 \leq \gamma \leq 1$ is a parameter; in Rothman, Hong, and Mount (1994), the term $(1 - w_i - w_j)$ is added to ensure all pairs of commodities are substitutes. ($\theta_{ij} = w_i^{-\gamma} w_j^{1-\gamma}(1 - w_i - w_j)$) Weng and Mount (1997) fits different values of δ and γ to find which is best, as does Dumagan and Mount (1993); the same is done in this study.

As shown in Dumagan and Mount (1993), another element that must be considered in the use of a generalized logit model is price scaling. If price scaling is given as a scalar β_j, then $\alpha_{ij}x_{ij} = \alpha_{ij}\theta_{ij}\log\left(\frac{(\beta_j\, p_j)}{p_i}\right) = \alpha_{ij}\theta_{ij}\log(\beta_j) + \alpha_{ij}\theta_{ij}\log\left(\frac{p_j}{p_i}\right)$; therefore, the parameters β_j need to be estimated.

The model specification used in this analysis, drawn from Weng and Mount (1997) is:

$$\log\left(\frac{w_{its}}{w_{nts}}\right) = (a_{i0s} - a_{n0s}) + \sum_{j=1, j\neq i}^{n}(\alpha_{ij}\theta_{ij(t-1)s}\log\left(\frac{p_{jts}}{p_{its}}\right)) - \sum_{j=1}^{n-1}(\alpha_{nj}\theta_{nj(t-1)s}\log\left(\frac{p_{jts}}{p_{nts}}\right))$$

$$+ \sum_{j=1, j\neq i}^{n}(\alpha_{ij}\theta_{ij(t-1)s}\log\left(\frac{\beta_j}{\beta_i}\right)) - \sum_{j=1}^{n-1}(\alpha_{nj}\theta_{nj(t-1)s}\log\left(\frac{\beta_j}{\beta_i}\right))$$

$$+ \lambda\left(\log\left(\frac{q_{i(t-1)s}}{q_{n(t-1)s}}\right)\right) + (e_{its} - e_{nts}) \qquad (12)$$

subject to $\alpha_{ij} = \alpha_{ji}$, $\beta_n = 1$, and $\alpha_{n0s} = 0$. The term s in this model is used to refer to the different sectors within manufacturing, where values of i and j, 1 through 6, refer to electricity, gas, oil, coal, capital, and labor, in order.

The model was estimated using RATS by Zellner's iterated seemingly-unrelated regression. In the model, $\alpha_{12} = \alpha_{13} = \alpha_{14}, \alpha_{25} = \alpha_{35} = \alpha_{45}$, and $\alpha_{26} = \alpha_{36} = \alpha_{46}$, was assumed, reflecting weak separability of the three fossil fuels.

2. Data

Annual data from 1990 to 2010 for the manufacturing industry and its sub-sectors is used. Energy consumption was retrieved from Yearbook of Energy Statistics in 1,000 toe units. Four major types of energy inputs were examined: coal, oil (petroleum), gas, and electricity. Coal consumption is categorized into anthracite-domestic, anthracite-import, bituminous-coking, and bituminous-steam. Because bituminous-coking is a material input rather than energy input, it was excluded from total coal consumption. Anthracite consumption cannot be distinguished between material and energy input, and hence both figures were included. Oil is categorized into three large categories: energy use, LPG, and non-energy use. Non-energy use was excluded from total oil consumption. Gas consumption comes from LNG or town gas. Most of gas consumption comes from town gas, but from 2010, the direct purchase of LNG by industry from importers became possible, and hence LNG consumption was included in total gas consumption. Electricity consumption data was used as provided in the Yearbook of Energy Statistics. In calculating the total cost of energy input, the calorific values were converted to original units for each respective energy input using the calorific balance table provided in the Monthly Energy Survey.

Data for coal price was provided by Korea Coal Association. The price used is price at time of import, and not price to industry consumers, because such data was unavailable. In reality retailor margin and tax is added to the import price, and hence some error in this respect could not be avoided. Price for oil and gas was taken from Yearly Energy Statistics and Monthly Energy Statistics. Price for electricity is from Statistics of Electric Power in Korea. Because the four energy inputs are sub-categorized to different types of energy inputs which are priced differently, a weighted average price was calculated for coal, oil, gas, and electricity. As such, even at the same time period, the price of each energy input varies across industries. Cost of energy inputs was calculated by multiplying total energy use and price.

Price of labor input was calculated using statistics from Report on Occupational Wage Survey from 1990 to 1992, and data retrieved from Korean Statistical Information Service for 1993-2010 (the data for 1993-2010 is from the same survey, however reporting format has been digitalized). Price was calculated as the average wage per hour. It was calculated based on monthly wage, yearly wage, and monthly hours worked. Cost of labor was retrieved from Income Statement of respective sectors (BOK, the Economic Statistics System). Salaries, retirement allowances, and other employee benefits were included from the Income Statement as labor costs. The quantity of labor was calculated by dividing cost of labor by price. Such calculations are a rough estimate of total quantity of labor, and does not account for the differences in the quality of each labor input. As such, a more detailed study into labor input is needed to explore the relationship between energy inputs and labor; however, the main purpose of this study is the own- and cross- price elasticities of energy inputs, and hence the issue was not explored further.

Capital stock figures were drawn from the KIP Database. The KIP Database uses modified perpetual inventory method and polynomial benchmark year estimation method using four benchmark-year estimates (KIP Database). With the year 2000 as the benchmark year, the estimation of national wealth by types of assets and industries made by Pyo (2003) is extended. The KIP Database classifies industry into 72 sub-industries, and assets were categorized into five categories: (1) residential building, (2) non-residential building, (3) infrastructure, (4) transportation equipment, and (5) machinery. Details of the methodology can be found in Pyo (2003). As in in Lee (1997), Kim (2007), and Kim and Huh (2010), cost of capital was calculated by subtracting employee income from net value added (excluding indirect tax) and dividing by producer price index to convert into real value. The data for employee income and net value added was obtained from Report on Mining and Manufacturing Survey, Report on the Economic Census , and Report on the Industrial Census for the respective years. Price of capital was deduced by dividing cost of capital by capital stock figures.

All the data was normalized using the producer price index available from BOK. A summary of the data used is provided in Table 3, 4, 5, and 6.

Table 3. Summary of data used for the manufacturing sector

	unit	average	stdev	total growth (1990 vs 2010)	avg yearly growth
p_elec	won/1000toe	328,747,721	29,239,379	-13.3%	-0.7%
p_gas	won/1000toe	399,780,852	111,289,474	74.6%	2.8%
p_oil	won/1000toe	535,145,863	298,387,697	466.1%	9.1%
p_coal	won/1000toe	116,962,695	42,948,612	95.1%	3.4%
p_K	won/won	0.433	0.057	-4.9%	-0.3%
p_L	won/hr	9,846	3,068	206.3%	5.8%
q_elec	1000toe	10,801	3,859	272.4%	6.8%
q_gas	1000toe	3,022	2,265	7783.0%	24.4%
q_oil	1000toe	11,862	3,337	-32.0%	-1.9%
q_coal	1000toe	5,684	1,540	42.6%	1.8%
q_K	won	509,502,480,537,543	202,887,383,952,021	301.2%	7.2%
q_L	hr	6,305,748,848	767,961,425	-16.6%	-0.9%
c_elec	won	3,491,235,423,812	1,164,316,547,045	222.9%	6.0%
c_gas	won	1,430,330,115,381	1,355,987,219,678	13661.6%	27.9%
c_oil	won	5,601,538,396,259	1,889,973,127,741	284.9%	7.0%
c_coal	won	646,732,940,938	230,741,823,061	178.3%	5.3%
c_K	won	212,263,593,275,034	69,812,341,509,733	281.5%	6.9%
c_L	won	60,527,157,533,945	15,509,555,351,712	155.4%	4.8%
s_elec	-	0.012	0.001	-7.9%	-0.4%
s_gas	-	0.004	0.003	3827.0%	20.1%
s_oil	-	0.020	0.007	9.8%	0.5%
s_coal	-	0.002	0.000	-20.6%	-1.1%
s_K	-	0.743	0.023	8.9%	0.4%
s_L	-	0.218	0.025	-27.1%	-1.6%

Table 4. Summary of data used for the petrochemical sector

	unit	average	stdev	total growth (1990 vs 2010)	yearly growth
p_elec	won/1000toe	328,747,721	29,239,379	-13.3%	-0.7%
p_gas	won/1000toe	399,322,076	110,370,879	71.8%	2.7%
p_oil	won/1000toe	584,284,926	318,769,670	554.4%	9.8%
p_coal	won/1000toe	113,641,888	43,488,907	98.0%	3.5%
p_K	won/won	0.391	0.104	-36.3%	-2.2%
p_L	won/hr	13,186	4,300	166.4%	5.0%
q_elec	1000toe	2,288	815	295.7%	7.1%
q_gas	1000toe	400	475	34771.9%	34.0%
q_oil	1000toe	4,182	1,875	23.4%	1.1%
q_coal	1000toe	145	26	13.2%	0.6%
q_K	won	77,026,106,906,538	31,453,801,422,536	359.3%	7.9%
q_L	hr	315,462,729	69,447,264	-16.0%	-0.9%
c_elec	won	739,426,387,174	245,771,458,547	243.1%	6.4%
c_gas	won	203,702,406,347	288,484,615,501	59824.5%	37.7%
c_oil	won	2,313,126,960,551	1,348,940,048,508	707.6%	11.0%
c_coal	won	15,831,148,313	4,291,934,779	124.0%	4.1%
c_K	won	27,367,857,042,631	7,154,096,882,087	192.6%	5.5%
c_L	won	3,921,445,427,978	726,409,224,117	123.8%	4.1%
s_elec	-	0.021	0.004	11.7%	0.6%
s_gas	-	0.005	0.006	19404.1%	30.2%
s_oil	-	0.066	0.043	162.8%	5.0%
s_coal	-	0.000	0.000	-27.1%	-1.6%
s_K	-	0.791	0.039	-4.8%	-0.2%
s_L	-	0.116	0.015	-27.2%	-1.6%

Table 5. Summary of data used for the non-metal sector

	unit	average	stdev	total growth (1990 vs 2010)	yearly growth
p_elec	won/1000toe	328,747,721	29,239,379	-13.3%	-0.7%
p_gas	won/1000toe	397,166,052	106,504,574	59.0%	2.3%
p_oil	won/1000toe	487,601,510	250,104,640	335.8%	7.6%
p_coal	won/1000toe	113,906,775	43,336,218	96.3%	3.4%
p_K	won/won	35.719	7.625	-34.9%	-2.1%
p_L	won/hr	9,000	2,444	169.4%	5.1%
q_elec	1000toe	799	138	106.4%	3.7%
q_gas	1000toe	258	190	4713.9%	21.4%
q_oil	1000toe	1,122	312	-39.8%	-2.5%
q_coal	1000toe	3,553	571	4.8%	0.2%
q_K	won	512,102,055,524	202,130,230,774	309.7%	7.3%
q_L	hr	625,428,021	98,962,386	-36.0%	-2.2%
c_elec	won	260,153,110,771	37,324,992,508	79.0%	3.0%
c_gas	won	119,384,381,303	112,441,186,193	7554.4%	24.2%
c_oil	won	481,975,412,519	140,489,662,233	162.5%	4.9%
c_coal	won	391,338,700,956	111,320,457,820	105.7%	3.7%
c_K	won	16,958,057,402,799	4,263,819,740,792	166.7%	5.0%
c_L	won	5,490,561,263,706	1,228,613,431,418	72.4%	2.8%
s_elec	-	0.011	0.002	-25.0%	-1.4%
s_gas	-	0.004	0.003	3108.1%	18.9%
s_oil	-	0.020	0.002	10.0%	0.5%
s_coal	-	0.017	0.004	-13.8%	-0.7%
s_K	-	0.713	0.023	11.8%	0.6%
s_L	-	0.234	0.022	-27.7%	-1.6%

Table 6. Summary of data used for iron & steel sector

	unit	average	stdev	total growth (1990 vs 2010)	yearly growth
p_elec	won/1000toe	328,747,721	29,239,379	-13.3%	-0.7%
p_gas	won/1000toe	400,332,519	112,436,189	77.9%	2.9%
p_oil	won/1000toe	441,272,421	242,738,216	404.5%	8.4%
p_coal	won/1000toe	168,037,162	157,698,507	25.0%	1.1%
p_K	won/won	28.065	3.882	-7.1%	-0.4%
p_L	won/hr	11,194	2,891	118.1%	4.0%
q_elec	1000toe	1,969	761	315.5%	7.4%
q_gas	1000toe	612	466	1459900.0%	61.5%
q_oil	1000toe	862	418	-71.4%	-6.1%
q_coal	1000toe	377	424	-99.7%	-25.1%
q_K	won	618,150,631,288	253,105,192,029	310.5%	7.3%
q_L	hr	288,774,829	28,206,792	17.7%	0.8%
c_elec	won	635,814,465,771	232,940,981,623	260.2%	6.6%
c_gas	won	291,712,927,583	276,636,236,189	9350.9%	25.5%
c_oil	won	295,365,165,195	69,410,967,077	44.2%	1.8%
c_coal	won	46,033,334,677	57,058,074,526	-99.6%	-24.2%
c_K	won	16,905,664,009,610	6,695,679,015,453	281.2%	6.9%
c_L	won	3,255,011,376,489	987,296,827,166	156.7%	4.8%
s_elec	-	0.030	0.004	-0.1%	0.0%
s_gas	-	0.011	0.008	2521.5%	17.7%
s_oil	-	0.015	0.005	-60.0%	-4.5%
s_coal	-	0.002	0.002	-99.9%	-28.9%
s_K	-	0.784	0.021	5.7%	0.3%
s_L	-	0.158	0.023	-28.8%	-1.7%

IV. Results & discussion

The generalized logit model was applied to the dataset encompassing six factor inputs, modeling the production function of the manufacturing sector and three sub-sectors (petrochemical, non-metal, and iron & steel). In adjusting the cross-price weight θ_{ij}, a grid search was conducted on γ. As mentioned above, previous studies use values of γ ranging from -1 to 1, and Weng and Mount (1997) and Dumagan and Mount (1993) conduct a grid search for the value of γ. There are no theoretical basis for employing a certain value of γ; in the applications of generalized logit models, different values of γ are applied, and a grid-search is conducted for this study to determine the best value of γ.

Tables 7, 8, 9, and 10 show the values of the parameters for the grid search of γ, estimated by seemingly unrelated regression (SURE) using WinRATS. (The program used is provided separately in the appendix.) The functional form used is explained in equation (12) in the methodology section above; numbers 1, 2, 3, 4, 5, and 6 refer to electricity, gas, oil, coal, capital, and labor, respectively; the values A1~A5 refer to a_{i0s} ; the values A12~A56 refer to α_{ij}; C1~C5 refer to log β_i. Most of the coefficients' t-stat significance is within 0.05, indicating the elasticity computed using these coefficients are statistically significant as well. For petrochemical and non-metal sector, the SURE did not converge for $\gamma = 0.0$, and the results are not reported. For some values of γ, the model converged in two solutions for the coefficients and the corresponding elasticities. In these cases, one of the solutions yielded estimates of positive own-price elasticities that diverged widely from the model with the γ value immediately preceding or following it in the grid search, and hence the point that continued the trend and showing negative own-price elasticities was selected.

Table 7. Coefficients for manufacturing sector

γ	-1	-0.5	-0.1	-0.05	-0.01	0	0.01	0.05	0.1	0.5	1
A1	7.2*	7.2*	7.7*	5.7*	4.6*	3707.6	-8.6	3.3	3.6*	5.1*	3.3*
A2	7.3*	7*	5.6*	5.9*	5.4*	28.9	5.1*	5.4*	5.5*	5.6*	4.6*
A3	7.4*	7.3*	6.1*	6.4*	6.1*	29.8	5.7*	5.7*	5.7*	5.9*	3.7*
A4	6.1*	6.1*	5.3*	5.6*	5.4*	29.2	5.2*	4.5*	4.5*	2.8*	1.5*
A5	-6.6*	-6.1*	-5.2*	-4.5*	-5.0*	800.9	-13.5	-9.2*	-8.6*	-5.8*	-4.4*
A12	-2122.4*	-62.1*	-0.7	-2.3*	-1.7*	-0.8*	-0.9*	-1.2*	-0.9*	0.0*	0.0
A15	-63.7*	-7.4*	-1.3*	-1*	-0.8*	-0.8*	-0.8*	-0.7*	-0.6*	-0.1*	0.0*
A16	-178.6*	-10.7*	-1.4*	-0.8*	-0.7*	-0.8*	-0.7*	-0.5*	-0.4*	0.0*	0.0*
A23	89384.2*	1724.8*	64.9*	42.6*	29.3*	30.7*	24.4*	12.4*	7.8*	0.2*	0.0
A24	-1505546*	-10256.4*	-127.2*	-78.2*	-46.9*	-38.9*	-35.3*	-6.7	-3.3	0.2	0.0
A25	-52.5*	-7.5*	-1.4*	-1.1*	-0.9*	-0.9*	-0.8*	-0.7*	-0.5*	-0.1*	0.0*
A26	32.4*	1.7	0.1	0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0*
A34	19927.4	231.7	5.2	2.8	1.0	1.1	0.8	-9.1*	-6*	-0.1*	0.0*
A56	-4.5*	-1.8*	-0.8*	-0.7*	-0.7*	-0.6*	-0.6*	-0.6*	-0.6*	-0.3*	0.0*
C1	-10.8*	-11.1*	-12.9*	-10.5*	-8.8*	-4861.2	9.5	-5.8	-6.7*	-10*	-9.5*
C2	-11.6*	-11.7*	-11.3*	-11.9*	-10.9*	-418	-7.1	-8.7*	-9.3*	-10.9*	40.6
C3	-11*	-11.3*	-10.9*	-11.6*	-10.5*	-417.7	-6.7	-8.2*	-8.8*	-11*	-12.1
C4	-10.3*	-10.6*	-10.7*	-11.3*	-10.4*	-417.7	-6.8	-7.3*	-7.8*	-7.6*	-10.1
C5	9.4*	9.1*	8.6*	7.4*	8*	-1285.1	21.4	13.7*	13.4*	10.2*	11.4*
LMD	0.7*	0.7*	0.7*	0.7*	0.7*	0.7*	0.7*	0.7*	0.7*	0.6*	0.5*

* t-stat significance is smaller than 0.05

Table 8. Coefficients for petrochemical sector

γ	-1	-0.5	-0.1	-0.05	-0.01	0.01	0.05	0.1	0.5	1
A1	8.2*	8.2*	7.2*	7.9*	-2.3	6.3*	6.4*	3.0	4.3*	3.9*
A2	7.2*	7.0*	10.4*	14.9*	48.7*	7.9*	6.9*	2.6	6.4*	4.7*
A3	8.4*	8.9*	13.3*	17.3*	51.4*	9.6*	8.7*	3.8*	4.9*	3.7*
A4	6.4*	7.4*	-29.4*	14*	-315.2*	7.6*	7.1*	1.8	5.6*	2.0*
A5	-8.2*	-8.5*	-4.7*	-5.8*	-4.6*	-5.9*	-6.3*	-10.5*	-5.5*	-4.5*
A12	-303.4*	-26.0 *	-2.1*	-1.5*	-1.1*	-1.0*	-0.8*	-0.7*	-0.1*	0.0
A15	-50.8*	-7.4*	-1.4*	-1.2*	-1.0*	-1.0*	-0.9*	-0.7*	-0.1*	0.0*
A16	-320.5*	-15.0*	-1.6*	-1.3*	-1.1*	-0.7*	-0.6*	-0.3*	0.0*	0.0*
A23	117.7	259.8*	35.3*	22.3*	18.9*	13.3*	10.5*	6.0*	0.0	0.0*
A24	33341.4	-7138.9*	-2.0*	12.9	-1.1*	10.6	11.9	8.8	0.2	0.0
A25	-11.5*	-4.6*	-1.5*	-1.3*	-1.1*	-0.9*	-0.7*	-0.6*	0.0*	0.0*
A26	21.3	-19.8*	-1.8*	-1.4*	-1.1*	-1.1*	-1.0*	-0.3*	0.0	0.0
A34	600.9	6.1	-1.9*	-3.6*	-1.1*	-2.3*	-1.6*	-1.6*	0.0*	0.0*
A56	-8.0*	-2.8*	-0.9*	-0.8*	-0.7*	-0.7*	-0.6*	-0.6*	-0.2*	-0.1*
C1	-10.2*	-10.1*	-11.5*	-11.3*	-1.8	-10.1*	-10.1*	-5.0*	-9.2*	-10.2*
C2	5.1	-13.9*	-18.0*	-20.9*	-54.3*	-14.4*	-13.5*	-6.5*	-13.9*	-11.8*
C3	-10.2*	-10.7*	-16.9*	-19.7*	-53.2*	-13.2*	-12.3*	-5.8*	-9.1*	-6.4*
C4	-11.5	-12.3*	28.8*	-18.2*	301.1*	-12.2*	-11.6*	-4.7*	-12.1*	-6.6*
C5	10.4*	10.7*	7.9*	8.7*	7.6*	9.5*	10.2*	16.4*	11.5*	10.1*
LMD	0.8*	0.8*	0.7*	0.7*	0.7*	0.7*	0.7*	0.7*	0.6*	0.5*

* t-stat significance is smaller than 0.05

Table 9. Coefficients for non-metal sector

γ	-1	-0.5	-0.1	-0.05	-0.01	0.01	0.05	0.1	0.5	1
A1	1.9*	2.6*	5.6*	7.6*	-0.2	3.0*	2.8*	2.4*	1.6*	-2.2*
A2	0.1	0.4	-2.7	-5.9*	-94.6*	76.9*	11.5*	7.8*	0.7	-3.1*
A3	2.1*	3.0*	5.5*	8.4*	-1.1	-6.5	5.7*	4.3*	2.5*	-1.4*
A4	2.8*	4.1*	9.4*	14.6*	-2.0	-7.5	4.6*	3.4*	2.1*	-1.5*
A5	-1.6*	-0.5	2.4	6.0	-17.6	-6.3*	1.3	-0.1	-1.0*	0.1
A12	7841.9*	54.4*	0.9	0.1	-0.6*	-0.7*	-1.2*	-0.9*	0.0*	0.0*
A15	43.3*	-3*	-0.5*	-0.5*	-0.4*	-0.4*	-0.5*	-0.3*	-0.1*	0.0*
A16	-613.5*	-27.1*	-3.1*	-2.3*	-1.8*	-1.5*	-1.4*	-1.1*	-0.1*	0.0*
A23	-1326.8	-160.4	-3.1*	-1.7*	-0.8*	-0.5*	-0.1	0.1	0.1*	0.0*
A24	-4846.3*	-146.5*	-3.1*	-1.6*	-0.7*	-0.5*	-0.5	-0.3	0.1*	0.0*
A25	-26.2*	-4.6*	-1.0*	-0.8*	-0.7*	-0.6*	-0.4*	-0.2*	-0.1*	0.0*
A26	-6.8	1.3	-0.4*	-0.5*	-0.6*	-0.7*	-1.8*	-1.4*	-0.1*	0.0*
A34	3417*	93.6*	1.7*	0.5	-10.6*	-7.1*	-0.5	-0.9	-0.1*	0.0*
A56	-2.1*	-1.0*	-0.6*	-0.6*	-0.6*	-0.5*	-0.4*	-0.3*	-0.1*	0.0
C1	-10.9*	-10.5*	-11.4*	-12.2*	-8.0*	-9.7*	-9.4*	-10.0*	-10.1*	-8.9*
C2	-0.5	-6.1*	-1.2	2.7	150*	-122.4*	-23.7*	-21.9*	-14.2*	-11.9*
C3	-8.2*	-11.6*	-14.4*	-18.9*	1.1	6.7	-11.0*	-10.9*	-10.6*	-7.5*
C4	-12.9*	-15.8*	-22.8*	-30.4*	2.6	8.2	-9.4*	-9.5*	-9.6*	-6.5*
C5	6.1*	2.9*	-3.1	-9.2	33.3*	13.7*	-2.3	0.7	4.7*	9.7*
LMD	0.4*	0.4*	0.5*	0.5*	0.5*	0.5*	0.6*	0.5*	0.4*	0.1*

* t-stat significance is smaller than 0.05

Table 10. Coefficients for iron & steel sector

γ	-1	-0.5	-0.1	-0.05	-0.01	0	0.01	0.05	0.1	0.5	1
A1	8.9*	8.9*	8.5*	8.1*	-0.2	7.7*	7.7*	-0.7	3.2	4.3*	4.3*
A2	7.0*	7.0*	2.6	1.3	-94.6*	1.3	1.6	-0.2	0.7	-1.3	2.0
A3	8.7*	8.7*	6.8*	5.9	-1.1	6.4	6.8	4.0	5.0*	4.6*	4.4*
A4	9.0*	9.0*	7.5*	6.7	-2.0	7.1	7.5	4.9	5.9*	4.3*	3.3*
A5	-5.5*	-5.5*	-4.7*	-4.9	-17.6	-4.3	-4.0	-5.9*	-4.9*	-2.9*	-1.8*
A12	-26.5*	-26.5*	-0.9	0.0	-0.6*	0.2	0.2	-0.5	-0.4	0.0	0.0
A15	-6.2*	-6.2*	-1.4*	-1.2*	-0.4*	-1.0*	-1.0*	-0.7*	-0.6*	-0.2*	0.0*
A16	-8.4*	-8.4*	-0.5	-0.3	-1.8*	-0.2	-0.1	-0.6*	-0.4*	0.0*	0.0*
A23	-171.1*	-171.1*	-11.7	-7.5	-0.8*	-4.4	-4.0	-3.1	-1.8	-0.2	0.0
A24	14440.2*	14440.2*	582.8*	389.7*	-0.7*	257.7*	237.4*	175.6*	116.3*	4.1*	0.1*
A25	0.3	0.3	0.4	0.3	-0.7*	0.3	0.3	0.3*	0.2*	0.0*	0.0
A26	-38.7*	-38.7*	-6.5*	-5.3*	-0.6*	-4.2*	-4.0*	-2.8*	-2.0*	-0.2*	0.0
A34	-357.8	-357.8	-25.3	-18.0	-10.6*	-11.9	-10.9	-8.0*	-5.1	0.1	0.0
A56	-1.3*	-1.3*	-0.6*	-0.5*	-0.6*	-0.4*	-0.4*	-0.4*	-0.3*	-0.2*	0.0*
C1	-9.6*	-9.6*	-10.4*	-9.6	-8.0*	-9.9	-10.3*	1.1	-4.2	-8.4*	-10.7*
C2	-17.0*	-17.0*	-14.5*	-14.0*	150.0*	-14.1*	-14.2*	-14.1*	-14.5*	-13.2*	-8.8*
C3	-12.4*	-12.4*	-11.6*	-11.4*	1.1	-11.6*	-11.8*	-11.3*	-11.7*	-13.3*	-13.8*
C4	-15.5*	-15.5*	-13.0*	-12.6*	2.6	-12.6*	-12.7*	-12.7*	-13*	-11.6*	-7.3*
C5	7.7*	7.7*	7.9*	8.8	33.3*	7.9	7.2	11.4*	9.8*	7.9*	5.2*
LMD	0.9*	0.9*	0.8*	0.7*	0.5*	0.7*	0.7*	0.7*	0.7*	0.5*	0.5*

* t-stat significance is smaller than 0.05

The own-price elasticity results, the number of positive own price elasticities for the 126 data points in the time series, and McElroy's R^2 for values of γ are listed in Table 11. The own-price elasticities listed in the table are calculated at the mean cost shares of each factor input. The own-price elasticities are mostly negative, but for some values of γ positive own-price elasticities are given, contrary to economic logic requiring the concavity of cost functions. This contradiction to the concavity of cost functions was explored further by calculating the own-price elasticity at each of the data points in the time series, and the number of violations is listed in the table. McElroy's R^2 for SURE was used to determine the fit of the model; the results show all the γ values give R^2 values larger than 0.9 (with the exception of the case of iron & steel sector, γ=1.0, which is negligible). The generalized logit model gives a good fit for the data points regardless of the value of γ.

According to Weng and Mount (1997), the estimated price elasticities for the different values of γ should first of all be logical and consistent with economic theory, meaning that the Eigen values of the Hicksian price effects should be non-positive. In the grid search conducted by Weng and Mount (1997), the best value of γ is found by finding the smallest determinant of the variance-covariance matrix of residuals across equations, which corresponds to the best fit of the model. Also, the results giving positive own-price elasticities are rejected as being invalid models, as they contradict economic theory.

In this study, the best value of γ was determined by checking for violations of the concavity of the cost function. As mentioned above in the section on econometric methodology, the conditional demand function used in this analysis must exhibit the following properties (Considine and Mount, 1984):

1) all levels of inputs must be non-negative

2) each function must be zero-degree homogeneous in prices

3) the N x N matrix of elements, $\partial Q_i / \partial P_j$, must be symmetric and negative semi-definite, implying that own-price effects are negative and cross-price effects are symmetric.

The first two qualities are guaranteed as they are used in the derivation of the final model specification, but to satisfy the third property, the negative semi-definiteness of $\partial Q_i / \partial P_j$ needs to be checked (the final model specification also satisfies the symmetric element, see Considine and Mount (1984)). According to Hunt (1984), the negative semi-definiteness can be checked with a less stringent requirement. Positive own-price elasticities arise only when there is non-concavity, or when the matrix is not negative semi-definite. Hence instead of checking for negative semi-definiteness, own-price elasticities are checked, and if they are non-positive at every data point, the negative semi-definite criterion is seen to be satisfied. Based on this requirement, the number of data points giving positive own-price elasticities were counted for each γ value, and listed in Table 16. The best choice of γ is 0.1, giving 6 violations, and is used in the following analysis.

Figures 1, 2, 3, and 4 graph the results from Table 11. In manufacturing, petrochemical, and iron & steel sectors, the own-price elasticity of oil exhibits positive values when γ approaches -1 or +1. Other factors mostly adhere to economic theory and their own-price elasticities are negative. Also, variations in the value of γ will result in making the elasticity of one factor input greater or lesser than the other, and because γ is determined empirically, the differences in magnitude of the own-price elasticities are not enough to declare conclusively that one factor is more elastic or inelastic than the other. However, some trends are clear; for the manufacturing sector, the large negative elasticities of gas and electricity are most prominent (Figure 1). Except for the own-price elasticity of oil when γ = -1, all values of own-price elasticities are between 0 and -1, indicating they are all price-inelastic.

The petrochemical sector, in Figure 2, shows positive own-price elasticities for gas and capital; while positive own-price elasticity of gas may be due to the fact that energy consumption is influenced by non-market influences such as government policy, this cannot be said for that of capital. The model has to be rejected for γ = -0.5, -1.0. The results for the non-metal sector are shown in Figure 3: labor is clearly more elastic than capital, but for the energy inputs their own-price elasticity values do not show a consistent trend. On the other hand, the trends for the iron & steel sector are clearly visible in Figure 4.

Changes in own-price elasticity values are less pronounced for different values of γ, and the own-price elasticities increase in magnitude for γ values closer to 1. Similar to other sectors, capital is more inelastic compared to labor, and gas is more elastic than electricity. Coal has large negative own-price elasticity, something unique to the iron & steel sector alone.

Tables 12, 13, 14, and 15 show all the own- and cross-price elasticity figures calculated using SURE at the average values of cost shares. The values were shown to two decimal points, and the 0.00 elasticity figures do not indicate zero elasticity, but a very small elasticity.

In Table 12, the results for the manufacturing sector shows oil demand is not influenced much by changes in price of the other fuel inputs. The cross-price elasticities are between -0.02 and 0.01 for all values of gamma; oil-capital and oil-labor are complements, although the cross-price elasticities are smaller than 0.2 (except for the case where γ=1.0, where the oil-capital cross-price elasticity is 0.41). Next, looking at gas, the cross-price elasticitiy of gas-oil is both negative and positive depending on the value of γ, but its values are close to zero, ranging between -0.02 and 0.03, indicating the price of oil does not affect gas factor input much. Gas consumption seems to be affected the most by price changes of electricity, and shows they are substitutes. Gas-coal shows a complementary relationship for γ values between -1.0 and 0.1, but for γ values 0.5 and 1.0, gas-coal are shown to be substitutes. As for the non-energy inputs, gas is a substitute for capital and labor, having positive cross-price elasticities for all values of γ. Mirroring the trend found in gas-electricity cross-price electricity, electricity is affected more by price changes in gas than any other energy input. The relationship between electricity-oil and electricity-coal is unclear, as the sign of the cross-price elasticity changes with γ values, but the magnitudes are close to zero, indicating electricity demand is not influenced to a strong degree by oil or coal. Again, like other energy inputs, electricity is a substitute for capital and labor. As noted earlier, coal and gas are complements (except for values estimated for γ=0.5, 1.0), and its relationship with oil and electricity cannot be defined. What is interesting to note is that its own-price elasticity is smaller (in absolute value) than its cross-price elasticity with electricity for γ=0.05, 0.1, 1.0. Perhaps with coal being the cheapest energy source, its factor demand is dependent more on the price of other energy inputs, but again, this relationship is dependent on the value of γ and the results are inconclusive. Capital and labor both exhibit positive and relatively small cross-price elasticities with other energy inputs, which indicates capital and labor can be substituted with energy to some degree, but not to great amounts.

Similar trends are found for the petrochemical, non-metal, and iron & steel sectors in Table 13, 14, and 15. The cross-price elasticities of the energy inputs are close to zero, indicating the prices of other fuels are not very relevant to factor demand. The own-price elasticities are much larger than the cross-price elasticities. For all three sub-sectors, capital and labor are not much affected by price changes in energy inputs. However, when it comes to the relationship between energy inputs and capital or labor, comparisons across different values of γ show not only the magnitude changing, but the signs of price elastiticies changing as well. Again, it would be an error to conclude from the bellow result that one factor input is a simple substitute or a compliment with the other, as the signs of the cross-price elasticities changed depending on $\boldsymbol{\gamma}$.

The fit of the model can be examined in Figures 5, 6, 7, and 8. LNSR refers to $\log\frac{w_i}{w_6}$, the observed values, and HEQ refers to the corresponding estimated values from the model. Again, numbers 1, 2, 3, 4, 5, and 6 refer to electricity, gas, oil, coal, capital, and labor, respectively.

Figure 9 compares the own-price elasticities across sectors for γ=0.1. Non-metal sector has comparatively smaller elasticities (in terms of absolute value), while amongst energy inputs gas and electricity have larger own-price elasticities, with the exception of coal for the iron sector. The effect of price on energy consumption differs depending on industry. For example, electricity's own-price elasticity is highest for the petrochemical sector, while it is very low for the non-metal sector.

Table 11. Hicksian own-price elasticities of each sector for different values of γ

	γ	oil	gas	elec	coal	K	L	No. of positive own-price elasticity**	R^2
1*	1	-0.43	-1.01	-0.87	-0.34	-0.18	-0.56	0	0.978
	0.5	-0.24	-0.59	-0.54	-0.22	-0.09	-0.32	0	0.977
	0.1	-0.19	-0.57	-0.44	-0.12	-0.08	-0.26	0	0.984
	0.05	-0.18	-0.55	-0.41	-0.11	-0.07	-0.24	0	0.983
	0.01	-0.17	-0.56	-0.44	-0.15	-0.08	-0.29	2	0.981
	0	-0.19	-0.60	-0.44	-0.15	-0.09	-0.30	3	0.980
	-0.01	-0.20	-0.56	-0.43	-0.14	-0.08	-0.29	3	0.981
	-0.05	-0.20	-0.57	-0.44	-0.15	-0.09	-0.30	3	0.981
	-0.1	-0.12	-0.59	-0.45	-0.19	-0.08	-0.30	3	0.981
	-0.5	-0.03	-0.60	-0.46	-0.23	-0.06	-0.23	10	0.981
	-1	0.14	-0.67	-0.56	-0.35	-0.06	-0.21	20	0.972
2*	1	-0.43	-0.58	-0.73	-0.24	-0.13	-0.41	18	0.977
	0.5	-0.36	-0.32	-0.54	-0.13	-0.09	-0.34	2	0.964
	0.1	-0.13	-0.41	-0.25	-0.10	-0.04	-0.27	4	0.971
	0.05	-0.04	-0.38	-0.15	-0.06	-0.04	-0.26	9	0.970
	0.01	-0.01	-0.36	-0.13	-0.06	-0.04	-0.25	5	0.970
	-0.01	-0.01	-0.36	-0.06	0.03	-0.04	-0.26	31	0.974
	-0.05	0.05	-0.34	-0.04	-0.05	-0.02	-0.20	34	0.972
	-0.1	0.06	-0.40	-0.05	-0.11	-0.03	-0.25	30	0.972
	-0.5	0.64	-0.59	-0.27	-0.35	0.02	-0.08	42	0.948
	-1	1.66	-0.91	-0.76	-0.97	0.07	-0.11	40	0.922
3*	1	-0.44	-0.41	-0.18	-0.38	-0.26	-0.68	0	0.952
	0.5	-0.27	-0.12	-0.09	-0.21	-0.19	-0.43	7	0.979
	0.1	-0.11	-0.09	-0.10	-0.13	-0.18	-0.38	2	0.969
	0.05	-0.07	-0.06	-0.08	-0.09	-0.15	-0.31	4	0.967
	0.01	-0.26	-0.33	-0.21	-0.25	-0.14	-0.35	0	0.940
	-0.01	-0.26	-0.39	-0.23	-0.28	-0.13	-0.32	0	0.934
	-0.05	-0.31	-0.43	-0.44	-0.42	-0.12	-0.31	0	0.930
	-0.1	-0.31	-0.50	-0.52	-0.49	-0.14	-0.34	0	0.922
	-0.5	-0.24	-0.70	-0.70	-0.63	-0.17	-0.43	0	0.909
	-1	-0.80	-0.88	-0.85	-0.78	-0.21	-0.44	0	0.935
4*	1	0.39	-1.99	-0.91	-7.40	-0.15	-0.55	19	0.652
	0.5	0.06	-1.09	-0.62	-5.15	-0.14	-0.36	15	0.904
	0.1	-0.10	-1.10	-0.58	-3.70	-0.15	-0.35	0	0.938
	0.05	-0.12	-1.05	-0.56	-3.57	-0.15	-0.33	0	0.940
	0.01	-0.19	-0.93	-0.46	-3.31	-0.15	-0.31	0	0.939
	0	-0.20	-0.93	-0.45	-3.28	-0.15	-0.31	0	0.940
	-0.01	-0.21	-0.92	-0.45	-3.26	-0.14	-0.31	0	0.940
	-0.05	-0.20	-0.91	-0.45	-3.21	-0.14	-0.31	0	0.942
	-0.1	-0.18	-0.91	-0.47	-3.14	-0.14	-0.31	0	0.943
	-0.5	-0.28	-0.87	-0.47	-2.52	-0.13	-0.35	0	0.953
	-1	-0.90	-0.97	-0.94	-1.01	-0.19	-0.70	0	0.953

*1, 2, 3, and 4 refer to manufacturing total, petrochemical, non-metal, and iron and steel, respectively

**Out of 126 own-price elasticities for the period 1990-2010 and the six factor inputs

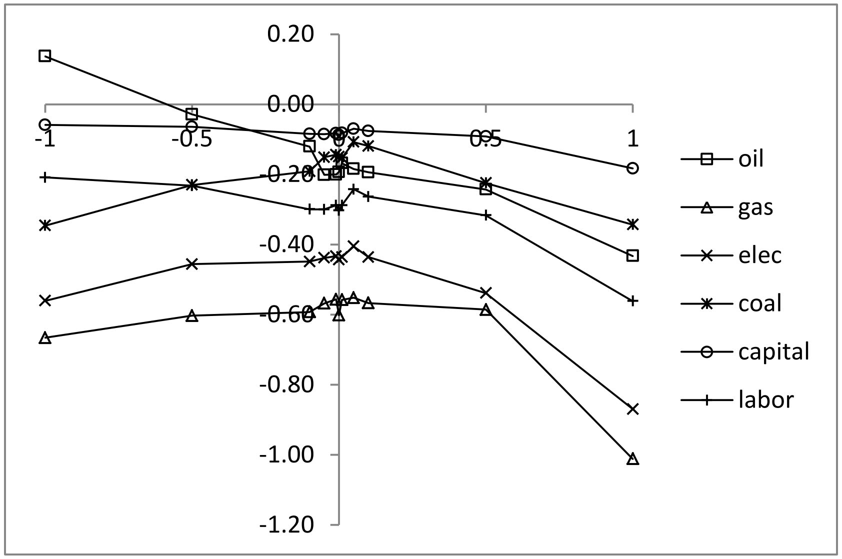

Figure 1. Hicksian own-price elasticity of manufacturing sector

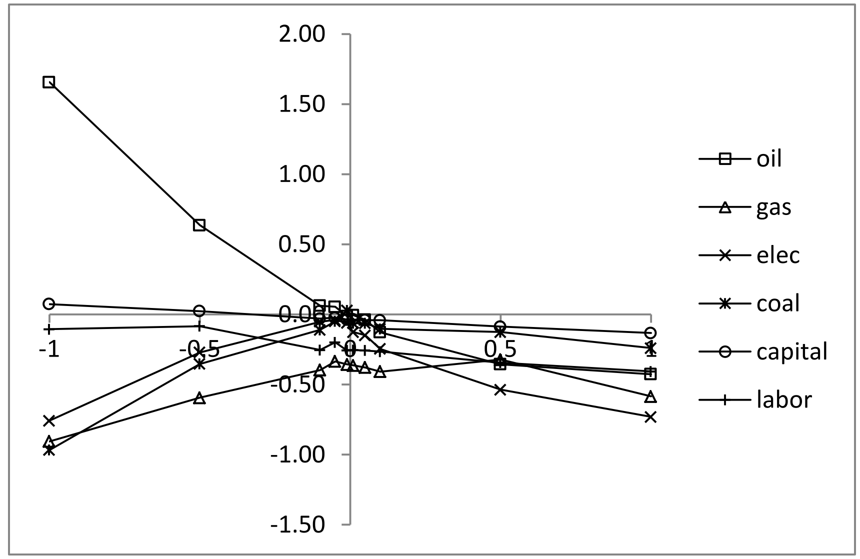

Figure 2. Hicksian own-price elasticity of petrochemical sector

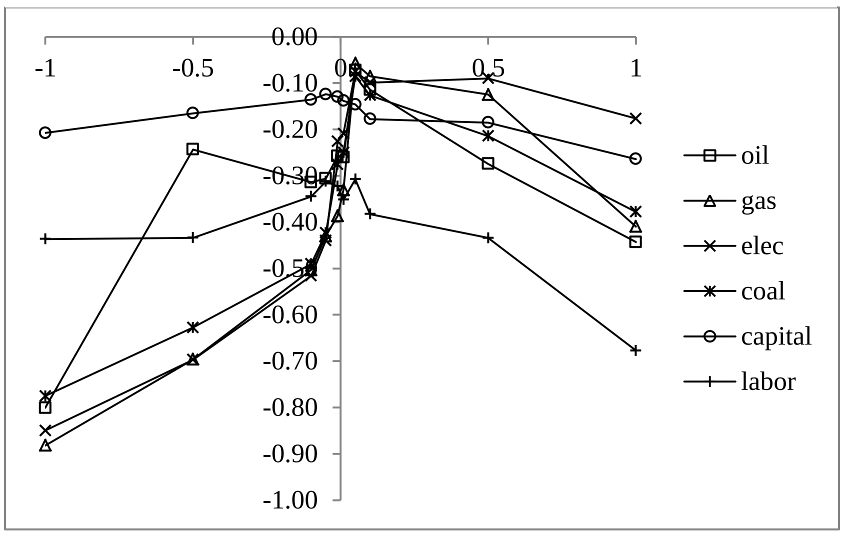

Figure 3. Hicksian own-price elasticity of non-metal sector

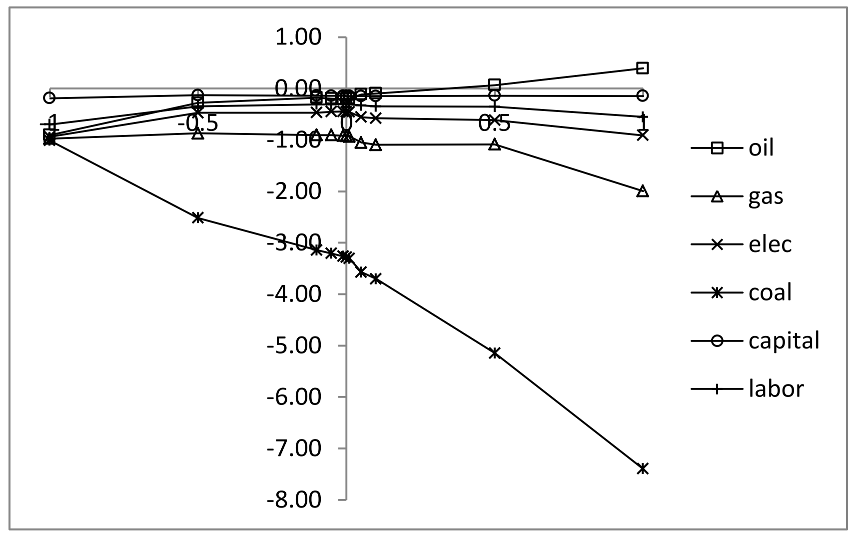

Figure 4. Hicksian own-price elasticity of iron & steel sector

Table12. Hicksian own- and cross-price elasticity for manufacturing sector for different values of γ

γ	-1.0	-0.5	-0.1	-0.05	-0.01	0.0	0.01	0.05	0.1	0.5	1.0
e-o	0.00	-0.01	0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.02	-0.01	0.02
e-g	0.07	0.11	0.13	0.13	0.13	0.14	0.12	0.09	0.09	0.09	0.01
e-e	-0.56	-0.46	-0.45	-0.44	-0.43	-0.44	-0.44	-0.41	-0.44	-0.54	-0.87
e-c	0.01	0.01	0.01	0.01	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.12
e-K	0.24	0.11	0.07	0.09	0.10	0.09	0.09	0.14	0.17	0.23	0.67
e-L	0.24	0.24	0.23	0.23	0.22	0.20	0.21	0.22	0.23	0.25	0.29
g-o	0.01	0.00	0.01	-0.01	-0.01	0.00	0.00	-0.02	-0.02	-0.02	0.03
g-g	-0.67	-0.60	-0.59	-0.57	-0.56	-0.60	-0.56	-0.55	-0.57	-0.59	-1.01
g-e	0.20	0.29	0.35	0.35	0.34	0.39	0.34	0.25	0.24	0.24	0.03
g-c	-0.24	-0.19	-0.11	-0.11	-0.10	-0.09	-0.09	-0.02	-0.02	0.06	0.01
g-K	0.47	0.27	0.11	0.11	0.10	0.09	0.09	0.12	0.13	0.05	0.60
g-L	0.23	0.23	0.23	0.23	0.22	0.20	0.21	0.22	0.23	0.26	0.35
o-o	0.14	-0.03	-0.12	-0.20	-0.20	-0.19	-0.17	-0.18	-0.19	-0.24	-0.43
o-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
o-e	0.00	0.00	0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	0.02
o-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
o-K	-0.14	-0.01	0.08	0.14	0.14	0.14	0.11	0.13	0.13	0.17	0.41
o-L	0.00	0.04	0.03	0.08	0.07	0.05	0.06	0.07	0.08	0.09	0.00
c-o	0.01	0.00	0.01	-0.01	-0.01	0.00	0.00	-0.02	-0.02	-0.02	0.03
c-g	-0.47	-0.38	-0.22	-0.21	-0.19	-0.17	-0.17	-0.04	-0.03	0.12	0.01
c-e	0.04	0.04	0.04	0.03	0.02	0.03	0.02	-0.16	-0.17	-0.08	-0.65
c-c	-0.35	-0.23	-0.19	-0.15	-0.14	-0.15	-0.15	-0.11	-0.12	-0.22	-0.34
c-K	0.53	0.33	0.13	0.12	0.10	0.09	0.09	0.12	0.11	-0.05	0.56
c-L	0.23	0.23	0.23	0.23	0.22	0.20	0.21	0.22	0.23	0.26	0.38
K-o	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
K-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K-e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
K-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K-K	-0.06	-0.06	-0.08	-0.09	-0.08	-0.09	-0.08	-0.07	-0.08	-0.09	-0.18
K-L	0.05	0.06	0.08	0.08	0.08	0.08	0.08	0.06	0.07	0.08	0.16
L-o	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00
L-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
L-e	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
L-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L-K	0.19	0.21	0.28	0.27	0.26	0.28	0.26	0.22	0.24	0.29	0.53
L-L	-0.21	-0.23	-0.30	-0.30	-0.29	-0.30	-0.29	-0.24	-0.26	-0.32	-0.56

Table13. Hicksian own- and cross-price elasticity for petrochemical sector for different values of γ

γ	-1.0	-0.5	-0.1	-0.05	-0.01	0.01	0.05	0.1	0.5	1.0
e-o	0.03	-0.01	-0.01	-0.01	0.00	-0.01	-0.01	-0.02	-0.08	0.01
e-g	0.01	0.03	0.09	0.09	0.11	0.09	0.10	0.08	0.01	-0.03
e-e	-0.76	-0.27	-0.05	-0.04	-0.06	-0.13	-0.15	-0.25	-0.54	-0.73
e-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
e-K	0.60	0.26	-0.04	-0.04	-0.04	0.07	0.10	0.12	0.54	0.61
e-L	0.12	-0.01	0.00	-0.01	0.00	-0.02	-0.04	0.06	0.07	0.21
g-o	0.05	0.02	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.17	-0.01
g-g	-0.91	-0.59	-0.40	-0.34	-0.36	-0.36	-0.38	-0.41	-0.32	-0.58
g-e	0.02	0.11	0.35	0.34	0.39	0.33	0.36	0.31	0.03	-0.08
g-c	0.00	-0.03	0.00	0.00	0.00	0.01	0.01	0.01	0.01	-0.02
g-K	0.71	0.45	0.03	0.00	-0.03	0.06	0.07	0.06	0.40	0.49
g-L	0.12	0.03	0.01	0.00	0.00	-0.02	-0.05	0.05	0.04	0.20
o-o	1.66	0.64	0.06	0.05	-0.01	-0.01	-0.04	-0.13	-0.36	-0.43
o-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00
o-e	0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.03	0.00
o-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
o-K	-1.48	-0.59	-0.06	-0.05	0.01	-0.02	0.01	0.08	0.34	0.32
o-L	-0.20	-0.04	0.00	0.00	0.00	0.02	0.03	0.05	0.06	0.11
c-o	0.06	0.03	0.00	0.00	0.00	-0.01	-0.01	-0.03	-0.26	-0.02
c-g	0.02	-0.31	0.00	0.05	0.00	0.07	0.12	0.14	0.15	-0.04
c-e	0.02	0.02	0.00	-0.03	0.00	-0.03	-0.03	-0.06	-0.02	-0.31
c-c	-0.97	-0.35	-0.11	-0.05	0.03	-0.06	-0.06	-0.10	-0.13	-0.24
c-K	0.75	0.55	0.08	0.03	-0.02	0.06	0.05	0.01	0.24	0.41
c-L	0.12	0.06	0.02	0.00	0.00	-0.02	-0.05	0.05	0.01	0.19
K-o	-0.12	-0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01
K-g	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K-e	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
K-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K-K	0.07	0.02	-0.03	-0.02	-0.04	-0.04	-0.04	-0.04	-0.09	-0.13
K-L	0.03	0.02	0.04	0.03	0.04	0.04	0.04	0.03	0.04	0.11
L-o	-0.11	-0.03	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.01
L-g	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L-e	0.02	0.00	0.00	0.00	0.00	0.00	-0.01	0.01	0.01	0.01
L-c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L-K	0.19	0.11	0.25	0.20	0.26	0.25	0.25	0.22	0.29	0.38
L-L	-0.11	-0.08	-0.25	-0.20	-0.26	-0.25	-0.26	-0.27	-0.34	-0.41

Table 14. Hicksian own- and cross-price elasticity for non-metal sector for different values of γ

γ	-1.0	-0.5	-0.1	-0.05	-0.01	0.01	0.05	0.1	0.5	1.0
e-o	0.09	0.04	0.03	0.02	0.01	0.00	-0.02	-0.02	-0.02	-0.03
e-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.13
e-e	-0.85	-0.70	-0.52	-0.44	-0.23	-0.21	-0.08	-0.10	-0.09	-0.18
e-c	0.04	0.05	0.03	0.02	-0.15	-0.11	0.00	-0.02	-0.09	-0.26
e-K	0.50	0.36	0.27	0.25	0.27	0.25	0.40	0.47	0.37	0.40
e-L	0.23	0.25	0.18	0.15	0.10	0.07	-0.32	-0.34	-0.22	-0.06
g-o	0.06	0.04	0.03	0.02	0.01	0.00	-0.02	-0.02	-0.04	-0.06
g-g	-0.88	-0.70	-0.50	-0.43	-0.39	-0.33	-0.06	-0.09	-0.12	-0.41
g-e	0.01	-0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.14	0.32
g-c	0.00	-0.02	-0.01	0.00	0.01	0.01	0.00	0.01	0.11	0.24
g-K	0.59	0.44	0.30	0.26	0.27	0.25	0.39	0.46	0.26	0.17
g-L	0.23	0.25	0.19	0.15	0.10	0.06	-0.33	-0.37	-0.35	-0.26
o-o	-0.80	-0.24	-0.31	-0.31	-0.26	-0.26	-0.07	-0.11	-0.27	-0.44
o-g	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01
o-e	0.05	0.02	0.02	0.01	0.01	0.00	-0.01	-0.01	-0.01	-0.02
o-c	0.09	0.04	0.02	0.02	0.01	0.00	-0.01	-0.02	-0.02	-0.01
o-K	1.27	0.43	0.47	0.45	0.41	0.39	0.27	0.34	0.44	0.63
o-L	-0.63	-0.26	-0.20	-0.18	-0.17	-0.13	-0.18	-0.20	-0.13	-0.14
c-o	0.11	0.05	0.03	0.02	0.01	0.00	-0.01	-0.02	-0.02	-0.02
c-g	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.06
c-e	0.03	0.03	0.02	0.01	-0.10	-0.08	0.00	-0.01	-0.06	-0.17
c-c	-0.78	-0.63	-0.49	-0.42	-0.28	-0.25	-0.09	-0.13	-0.21	-0.38
c-K	0.42	0.30	0.26	0.24	0.27	0.25	0.40	0.48	0.42	0.48
c-L	0.22	0.26	0.18	0.15	0.10	0.07	-0.31	-0.32	-0.15	0.02
K-o	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
K-g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K-e	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
K-c	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
K-K	-0.21	-0.17	-0.14	-0.12	-0.13	-0.14	-0.15	-0.18	-0.19	-0.26
K-L	0.15	0.14	0.11	0.10	0.11	0.12	0.12	0.15	0.15	0.23
L-o	-0.05	-0.02	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01
L-g	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01
L-e	0.01	0.01	0.01	0.01	0.00	0.00	-0.02	-0.02	-0.01	0.00
L-c	0.02	0.02	0.01	0.01	0.01	0.00	-0.02	-0.02	-0.01	0.00
L-K	0.46	0.42	0.34	0.31	0.32	0.35	0.37	0.45	0.47	0.70
L-L	-0.44	-0.43	-0.34	-0.31	-0.32	-0.35	-0.31	-0.38	-0.43	-0.68

Table 15. Hicksian own- and cross-price elasticity for iron & steel sector for different values of γ

γ	-1.0	-0.5	-0.1	-0.05	-0.01	0.0	0.01	0.05	0.1	0.5	1.0
e-o	0.01	0.00	0.01	0.02	0.01	0.02	0.02	0.00	0.00	0.02	0.02
e-g	0.01	-0.04	-0.05	-0.05	0.00	-0.04	-0.04	-0.04	-0.03	-0.09	0.05
e-e	-0.94	-0.47	-0.47	-0.45	-0.23	-0.45	-0.46	-0.56	-0.58	-0.62	-0.91
e-c	0.00	-0.01	-0.02	-0.02	-0.15	-0.02	-0.02	-0.02	-0.02	0.02	0.01
e-K	0.79	0.82	0.99	0.99	0.27	1.01	1.01	1.02	1.01	0.94	0.76
e-L	0.12	-0.30	-0.46	-0.49	0.10	-0.51	-0.50	-0.41	-0.38	-0.27	0.08
g-o	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.00	0.00	0.03	0.03
g-g	-0.97	-0.87	-0.91	-0.91	-0.39	-0.93	-0.93	-1.05	-1.10	-1.09	-1.99
g-e	0.03	-0.10	-0.14	-0.13	0.00	-0.10	-0.10	-0.11	-0.09	-0.24	0.12
g-c	0.01	0.31	0.47	0.49	0.01	0.51	0.52	0.55	0.57	0.75	1.13
g-K	0.79	0.81	0.98	0.99	0.27	1.01	1.01	1.03	1.03	1.01	0.73
g-L	0.14	-0.16	-0.41	-0.46	0.10	-0.51	-0.51	-0.43	-0.42	-0.46	-0.01
o-o	-0.90	-0.28	-0.18	-0.20	-0.26	-0.20	-0.19	-0.12	-0.10	0.06	0.39
o-g	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.02	0.02
o-e	0.03	0.01	0.02	0.03	0.01	0.04	0.04	0.01	0.01	0.05	0.04
o-c	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
o-K	0.71	0.18	0.04	0.02	0.41	0.01	0.01	0.07	0.05	-0.20	-0.32
o-L	0.15	0.08	0.11	0.13	-0.17	0.13	0.14	0.03	0.03	0.06	-0.14
c-o	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.00	0.00	0.03	0.04
c-g	0.03	1.90	2.84	2.98	0.00	3.10	3.13	3.32	3.45	4.50	6.81
c-e	0.03	-0.14	-0.31	-0.33	-0.10	-0.33	-0.33	-0.34	-0.33	0.28	0.15
c-c	-1.01	-2.52	-3.14	-3.21	-0.28	-3.28	-3.31	-3.57	-3.70	-5.15	-7.40
c-K	0.78	0.80	0.96	0.98	0.27	1.01	1.01	1.04	1.05	1.13	0.66
c-L	0.15	-0.05	-0.36	-0.44	0.10	-0.51	-0.52	-0.45	-0.48	-0.80	-0.25
K-o	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	-0.01
K-g	0.01	0.01	0.01	0.02	0.00	0.02	0.02	0.02	0.02	0.02	0.01
K-e	0.03	0.03	0.04	0.04	0.00	0.04	0.04	0.04	0.04	0.04	0.03
K-c	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K-K	-0.19	-0.13	-0.14	-0.14	-0.13	-0.15	-0.15	-0.15	-0.15	-0.14	-0.15
K-L	0.13	0.08	0.08	0.09	0.11	0.09	0.09	0.09	0.09	0.09	0.11
L-o	0.01	0.01	0.01	0.01	-0.01	0.01	0.01	0.00	0.00	0.01	-0.01
L-g	0.01	-0.01	-0.03	-0.04	0.00	-0.04	-0.04	-0.03	-0.03	-0.03	0.00
L-e	0.02	-0.06	-0.09	-0.09	0.00	-0.10	-0.10	-0.08	-0.07	-0.05	0.01
L-c	0.00	0.00	0.00	-0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.00
L-K	0.65	0.41	0.42	0.43	0.32	0.44	0.44	0.44	0.46	0.45	0.56
L-L	-0.70	-0.35	-0.31	-0.31	-0.32	-0.31	-0.31	-0.33	-0.35	-0.36	-0.55

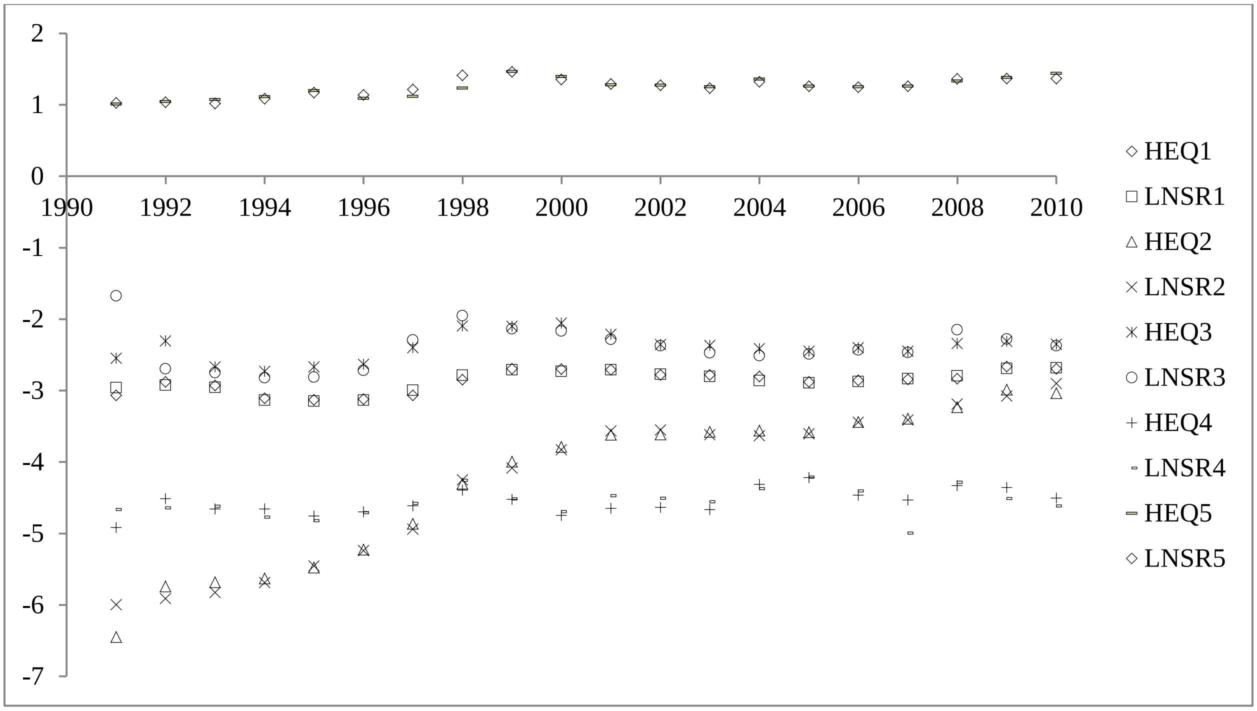

Figure 5. Observed and modeled values (manufacturing sector, γ =0.1; R^2=0.984)

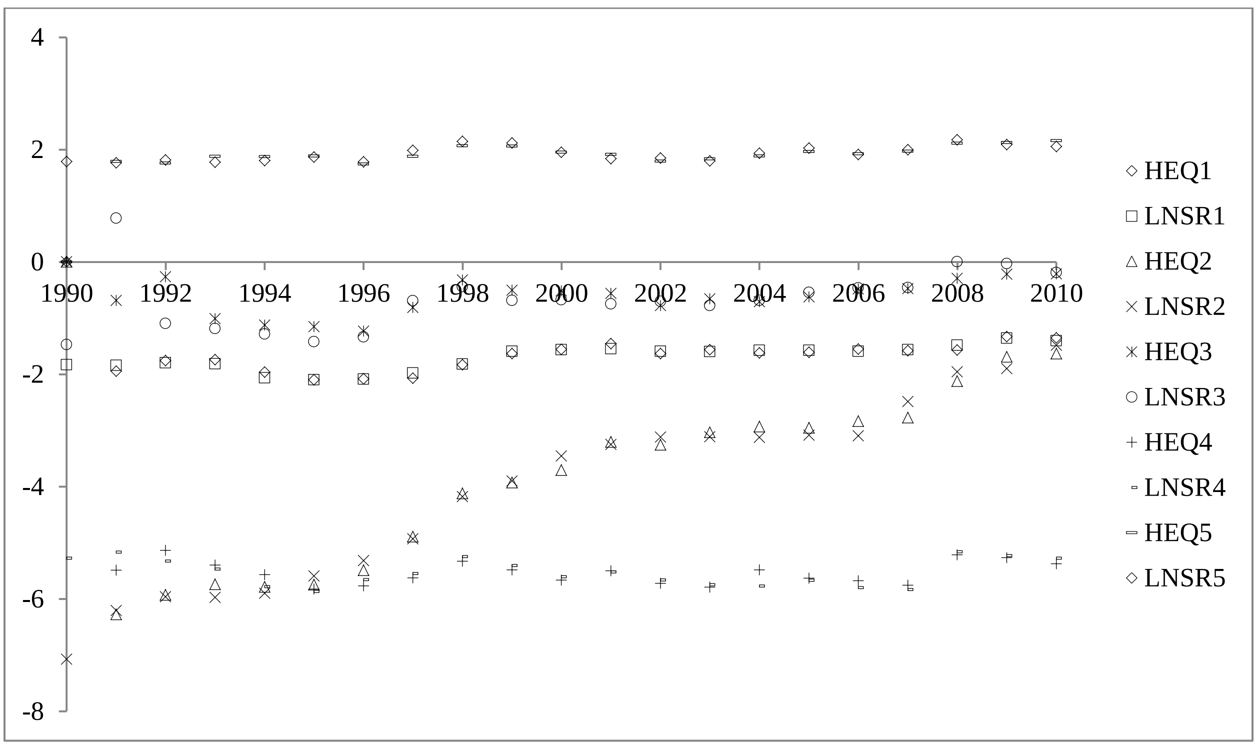

Figure 6. Observed and modeled values (petrochemical sector, γ =0.1; R^2=0.971)

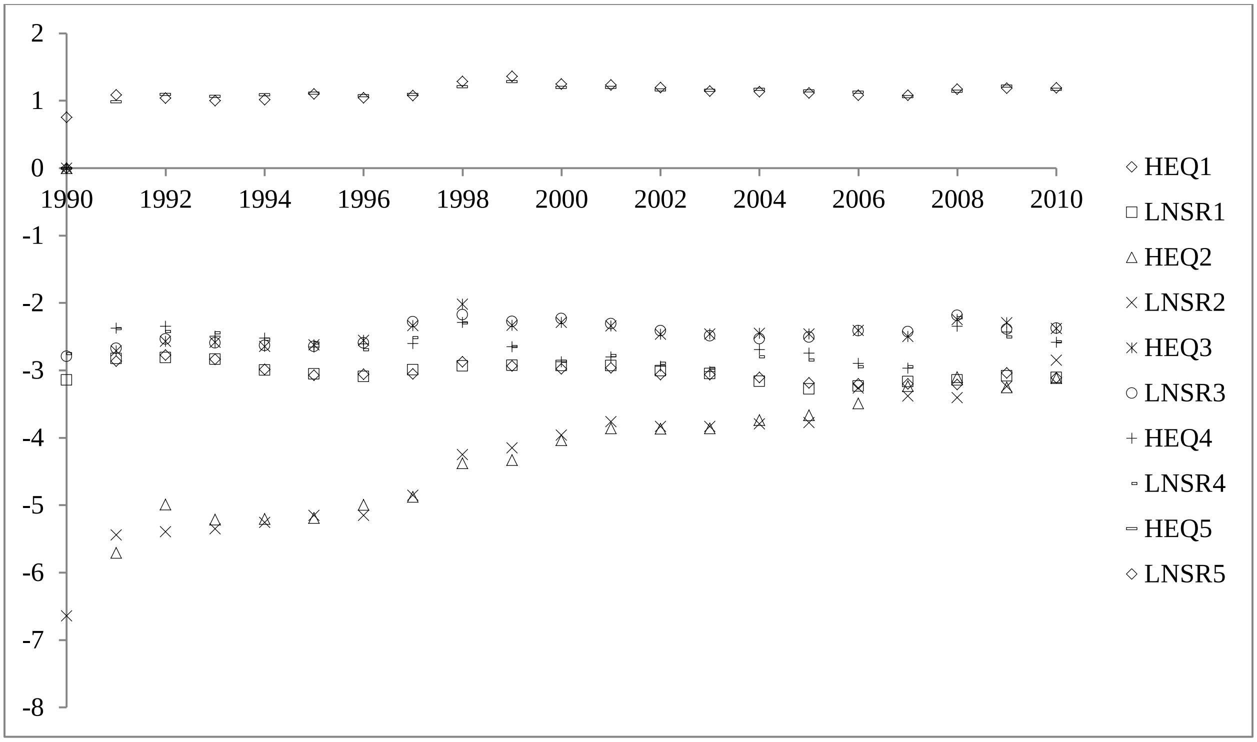

Figure 7. Observed and modeled values (non-metal sector, γ =0.1; R^2=0.969)

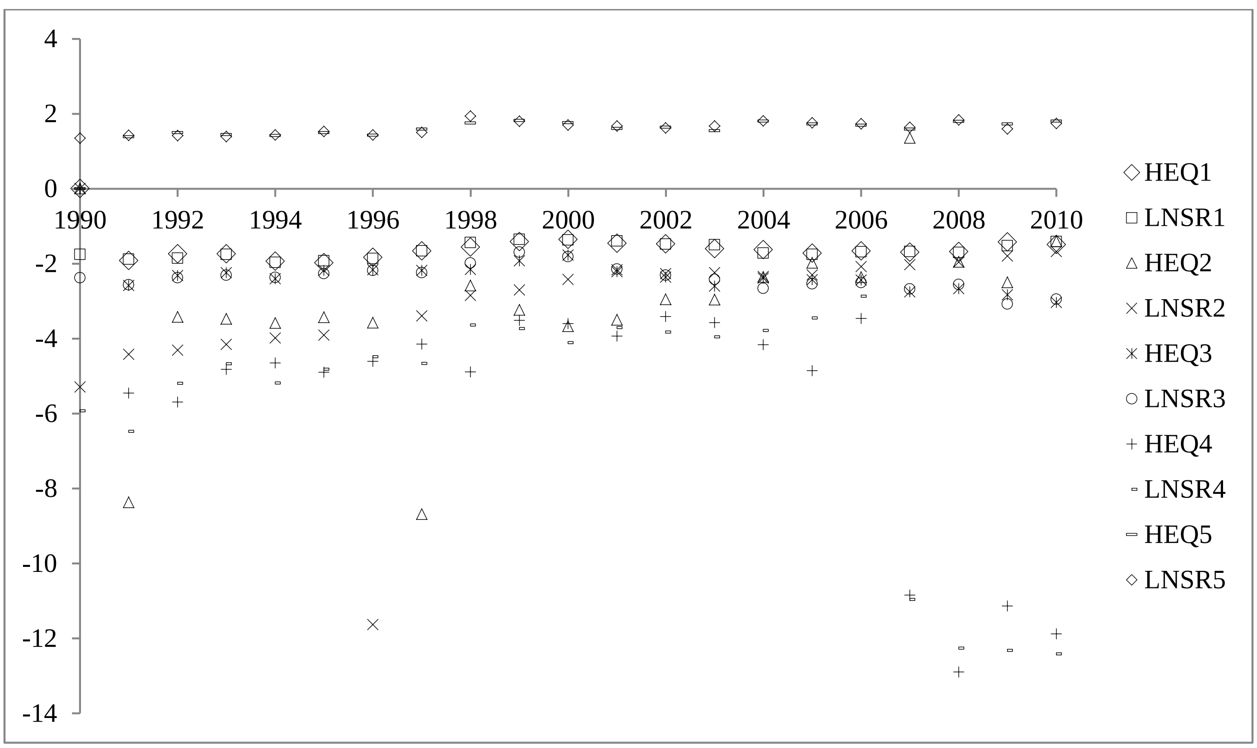

Figure 8. Observed and modeled values (iron & steel sector, γ =0.1; R^2=0.938)

Table 16. Number of positive own-price elasticities for different values of γ *

γ	man	petro	nonm	iron	sum
1	0	18	0	19	37
0.5	0	2	7	15	24
0.1	0	4	2	0	6
0.05	0	9	4	0	13
0.01	2	5	0	0	7
-0.01	3	31	0	0	34
-0.05	3	34	0	0	37
-0.1	3	30	0	0	33
-0.5	10	42	0	0	52
-1	20	40	0	0	60

*Out of 126 own-price elasticities for the period 1990-2010 and the six factor inputs

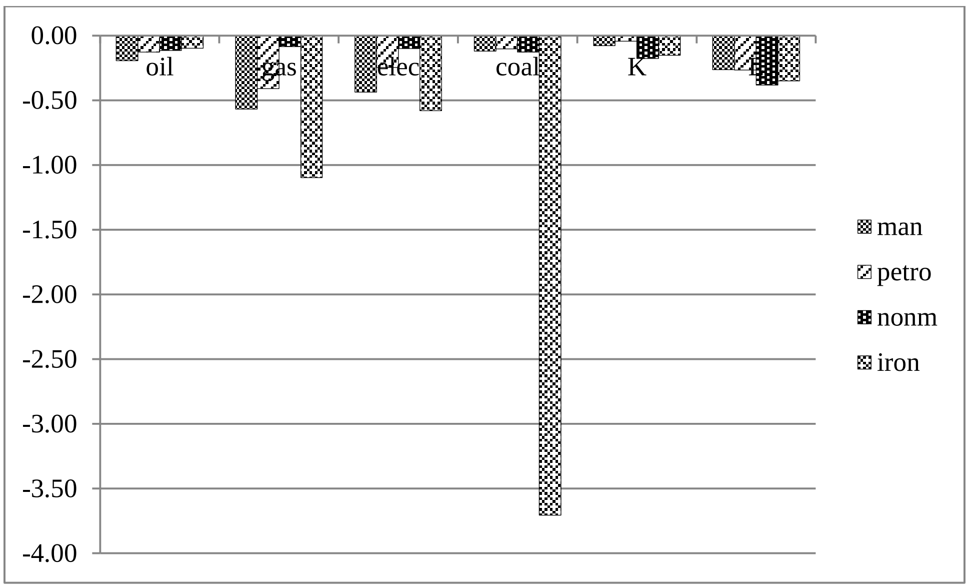

Figure 9. Hicksian own-price elasticities by sector for γ=0.1

In addition, Table 17 compares the results with Kim (2007), which was similar to this study in that the manufacturing sectors were analyzed by 11 sub-sectors. The period is also similar, using a time series data from 1990-2004. The two-stage translog function was used, while capital, labor, output yield, coal, oil, gas, and electricity were the factor inputs. The period covered is shorter in Kim (2007), but the sectors studied are the same. Oil, gas, and coal show positive own-price elasticities for Kim (2007), while results from this paper do not show positive own-price elasticities for the factor inputs. The generalized logit model is more appropriate to model producer behavior in this case.

Table 17. Comparison of elasticity results from Kim (2007)

	Kim (2007) (1990-2004)			This paper (1990-2010)		
factors	petro	nonm	iron	petro	nonm	iron
e-o	0.474	-0.582	0.084	0.005	-0.025	0.004
e-g	-0.234	-0.192	-0.255	-0.028	0.058	-0.038
e-e	-0.071	-1.195	-0.510	-0.731	-0.090	-0.473
e-c	0.001	-0.458	0.033	-0.057	-0.095	-0.009
g-o	2.106	0.118	0.275	-0.007	-0.038	0.008
g-g	9.464	0.708	4.333	-0.585	-0.125	-0.872
g-e	-11.399	-1.412	-5.632	-0.077	0.143	-0.097
g-c	0.000	-1.842	0.375	-0.019	0.111	0.315
o-o	0.012	-1.214	-1.391	-0.426	-0.274	-0.280
o-g	0.013	0.024	0.081	-0.002	-0.009	0.006
o-e	0.145	-0.862	0.544	0.003	-0.014	0.009
o-c	-0.002	-0.376	0.117	-0.002	-0.015	0.001
c-o	-0.834	-0.543	0.059	-0.016	-0.018	0.010
c-g	-0.001	-0.536	0.055	-0.038	0.030	1.897
c-e	0.096	-0.981	0.107	-0.311	-0.062	-0.141
c-c	0.916	-0.368	-0.869	-0.241	-0.214	-2.518

V. Conclusion

Many previous studies have investigated the price elasticity of energy input by sector. This paper continues the enquiry with the purpose of providing useful information to policy makers to implement price controls in controlling energy consumption by the manufacturing sector.

After examining the data for 1990-2010 for manufacturing sector as a whole and its three sub-sectors, the petrochemical, non-metal, and iron & steel sector, some expectations have indeed been proven true. The price elasticities do defer by sector, as is expected based on the different technologies and types of capital employed by each sector in the production process. However, the magnitude of own-price elasticities are between -1 and 0, showing the energy inputs to be price inelastic. The cross-price elasticities are much smaller in magnitude, indicating the price of other energy inputs does not have a strong effect on the amount of other energy inputs consumed in the process of production.

Another purpose of the study was to apply the generalized logit model and provide a different perspective to previous studies that used the translog model. In the process, a grid search on γ, one of the variables for the cross-price weight, was conducted. By doing so, this was a de-facto application of a number of models that have been applied for the study of price elasticity in the past (this refers to the models used in: Considine and Mount (1984), Dumagan (1992), Rothman, Hong, and Mount (1994)). The effect of the cross-price weight was studied, and after investigating that the own-price elasticities are non-negative at every point, the value of delta giving the least number of positive own-price elasticity for the dataset was found to be 0.1. The determination of the value of gamma was done on an empirical basis, and is not based on any economic theory. This limits the interpretation of the estimated price elasticities; no one value of γ was found to be superior to the other, while each value of γ yielded different elasticity results indicating the factor inputs to be complements in some cases and substitutes in others. Also, comparison of the magnitude of own-price elasticities became difficult, as they changed with the value of γ as well.

Although the own-price elasticities were inelastic, this does not mean price measures will not be effective in curbing growing energy consumption. According to the results, hypothetically a 1% increase in price will results in a 0.44% decrease in electricity consumption; a 0.57% decrease in gas consumption; a 0.19% decrease in oil consumption; and a 0.12% decrease in coal consumption in the manufacturing sector. With further understanding on the technical side of the production process that impacts energy consumption, such an economic model as applied in this paper should be part of a larger model able to describe the energy consumption behaviors of producers in a world that is driven by market mechanisms as part of a larger complex system.

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VII. Appendix

1. Zellner's seemingly unrelated regression equations and McElroy's R^2

Zellner's SURE is used in studies applying the generalized logit model. While SURE is standard practice, a brief review of the model and McElroy's R^2 from McElroy (1977) and Neudecker (1991) is presented to check the underlying assumptions and applicability to the model.

Zellner's model consists of n observations on L seemingly unrelated stochastic equations:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_g \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & & \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & X_g \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_g \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_g \end{bmatrix} \qquad (1)$$

where for the j-th equation y_j is n times 1, X_j is n times k_j of rank k_j and fixed, β_j is k_j times 1 and unknown, and ϵ_j is n times 1 and stochastic with mean zero. Assuming all expressions to include a constant term, X_j can be partitioned as (s_n, Z_j) ($s_n = (1, 1, \ldots, 1)'$ for all j). Writing (1) in compact form:

$$y = X\beta + \varepsilon \qquad (2)$$

where y and ε are n_g times 1, X is n_g times k, β is k times 1 and $k = \sum_{j=1}^{g} k_j$.

For ε, $E(\varepsilon)=0$ and $var(\varepsilon)=\Omega \otimes I_n$, Ω being the g x g positive definite contemporaneous variance.

(2) can be rewritten as

$$y = Z\beta_z + W\beta_w + \varepsilon, \qquad (3)$$

$$Z = \begin{bmatrix} Z_1 & 0 & \cdots & 0 \\ 0 & Z_2 & & \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & Z_g \end{bmatrix}, \qquad W = I_g \otimes s_n. \qquad (4)$$

(2) and (3) can be written as

$$y = Xb + e = Zb_z + Wb_w + e,$$

where

$$b = (X' (\Omega^{-1} \otimes I_n)X)^{-1}X' (\Omega^{-1} \otimes I_n)y.$$

The theoretical value of y, $\hat{y}$, is given by

$$\hat{y} = Xb = Zb_z + Wb_w. \qquad (5)$$

From (3) and (4) it follows that

$$X'(\Omega^{-1} \otimes I_n)e = 0; \left(I_g \otimes s_n{}'\right)e = 0; \left(I_g \otimes N_n\right)e = e. \qquad (6)$$

From the above, McElroy defines as a measure of goodness of fit for the estimated model

$$R_z^2 = \frac{b_Z' Z' (\Omega^{-1} \otimes N_n) Z b_z}{y' (\Omega^{-1} \otimes N_n) y} = \frac{\hat{y}' (\Omega^{-1} \otimes N_n) \hat{y}}{y' (\Omega^{-1} \otimes N_n) y}$$

where

$$N_n = I_n - n^{-1} s_n s_n{}', \qquad (7)$$

and the second equality holds because $W' (\Omega^{-1} \otimes N_n)=0$ by virtue of (4), (5), and (7). R_z^2 can be seen as the ratio of the estimated weighted variation to the total weighted variation in y, where y_j is measured as deviation from the mean of the jth equation, j=1,…,g.

2. Data used for analysis

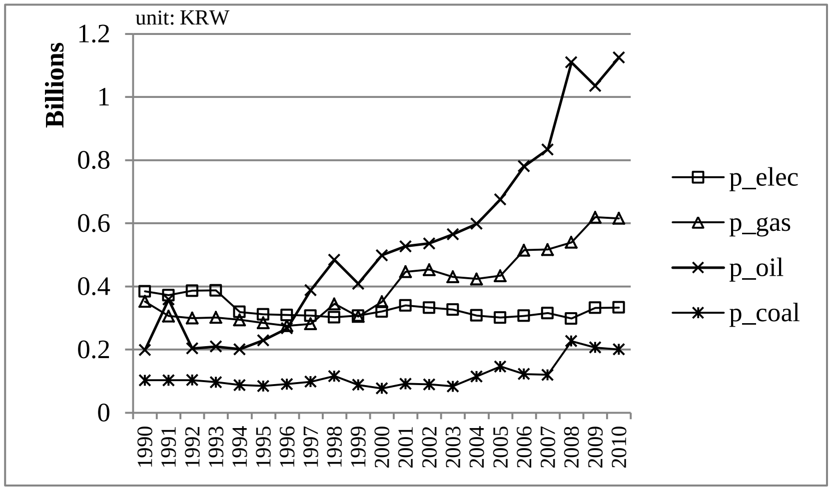

Figure10. Price of energy inputs for manufacturing sector

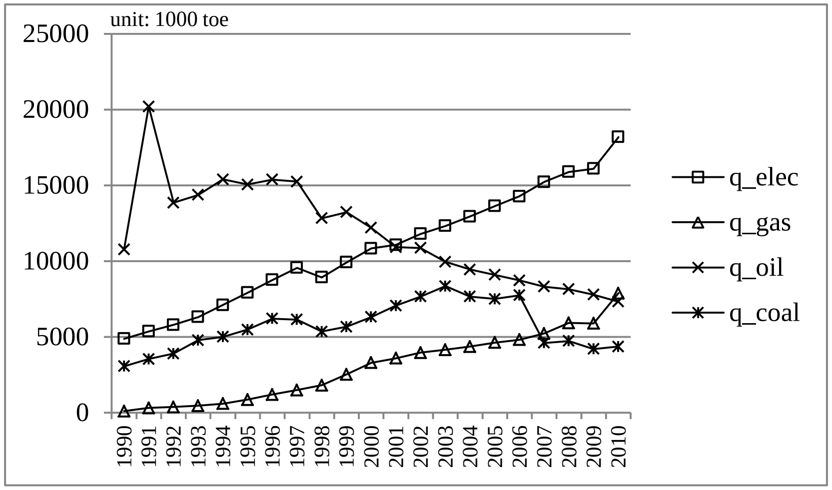

Figure 11. Quantity of energy inputs for manufacturing sector

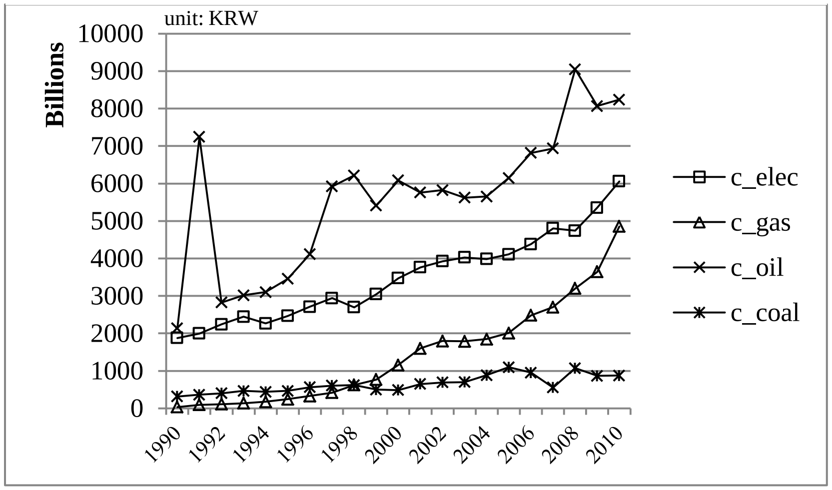

Figure 12. Cost of energy inputs for manufacturing sector

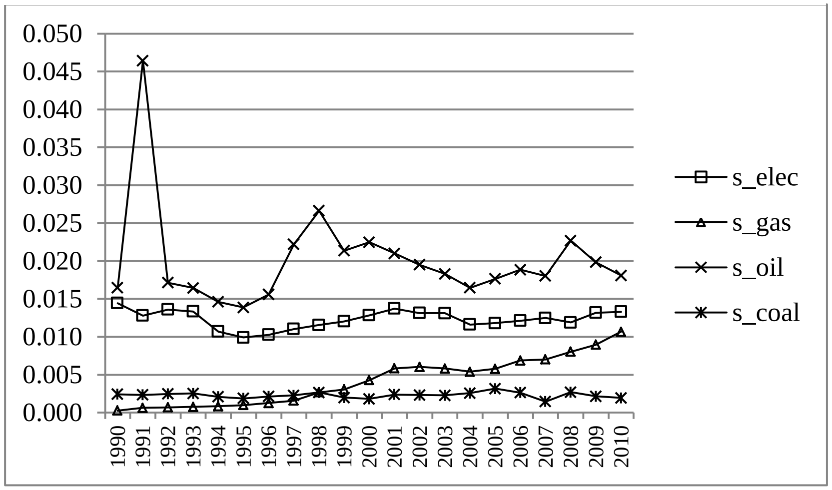

Figure 13. Cost share of energy inputs for manufacturing sector

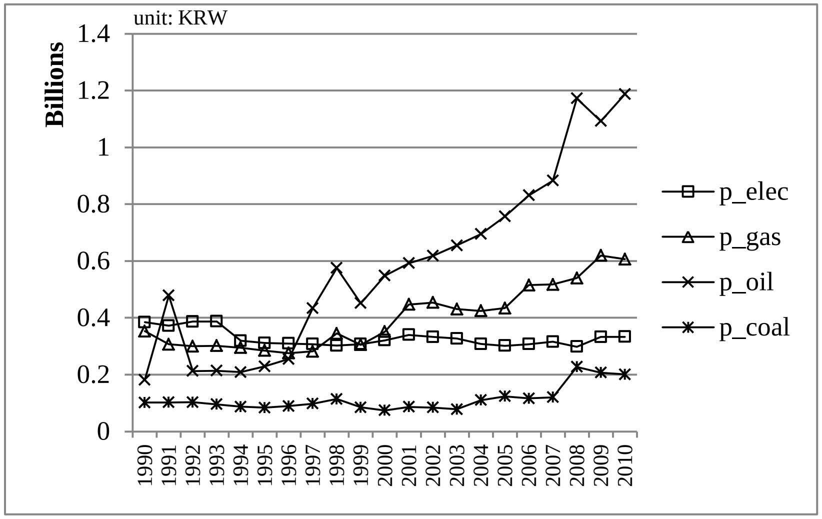

Figure 14. Price of energy inputs for petrochemical sector

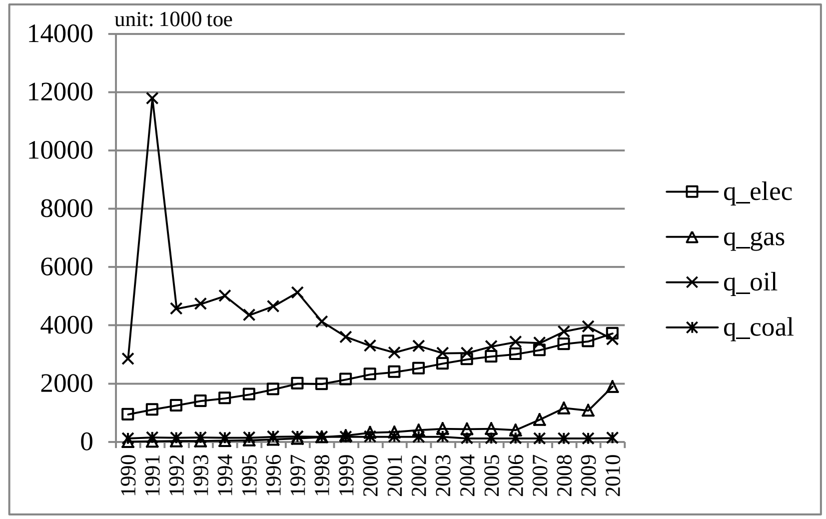

Figure 15. Quantity of energy inputs for petrochemical sector

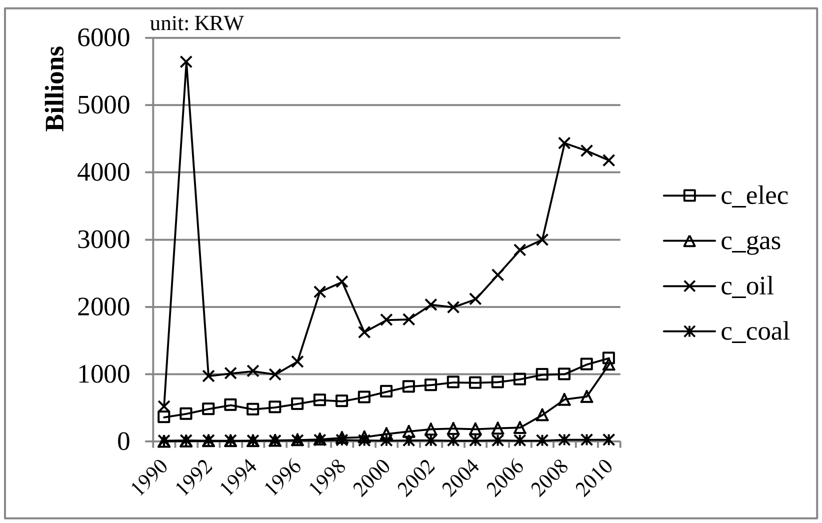

Figure 16. Cost of energy inputs for petrochemical sector

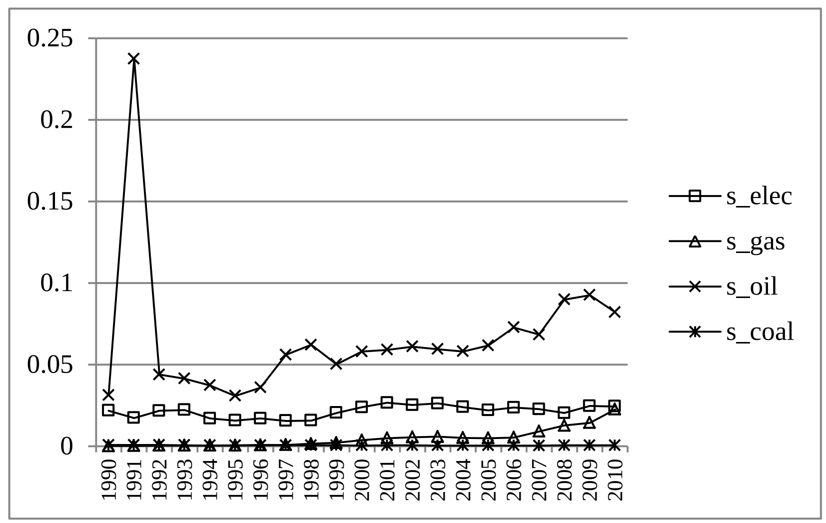

Figure 17. Cost share of energy inputs for petrochemical sector

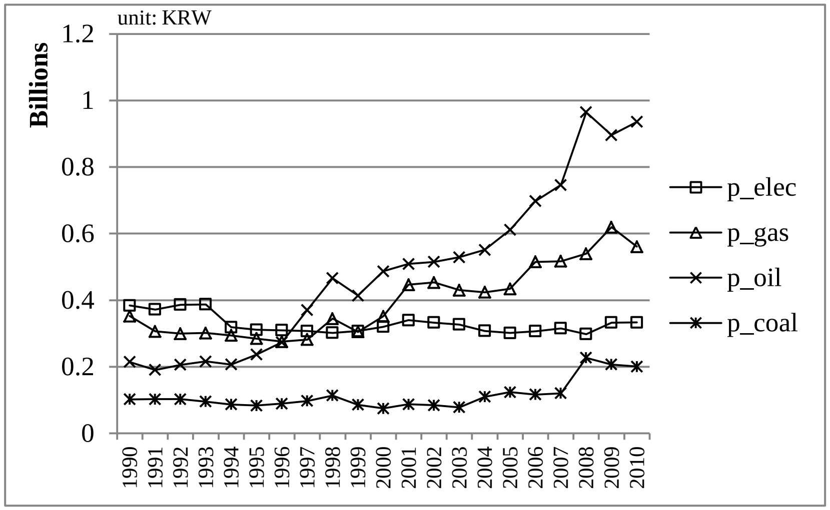

Figure 18. Price of energy inputs for non-metal sector

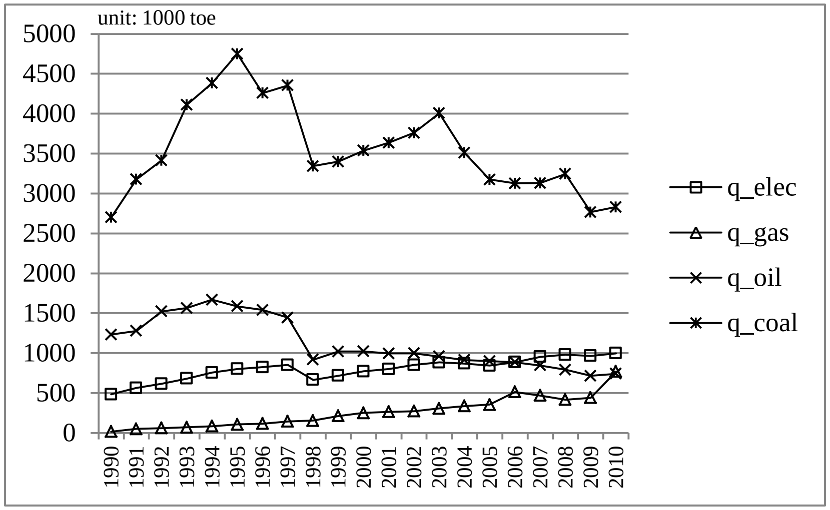

Figure 19. Quantity of energy inputs for non-metal sector

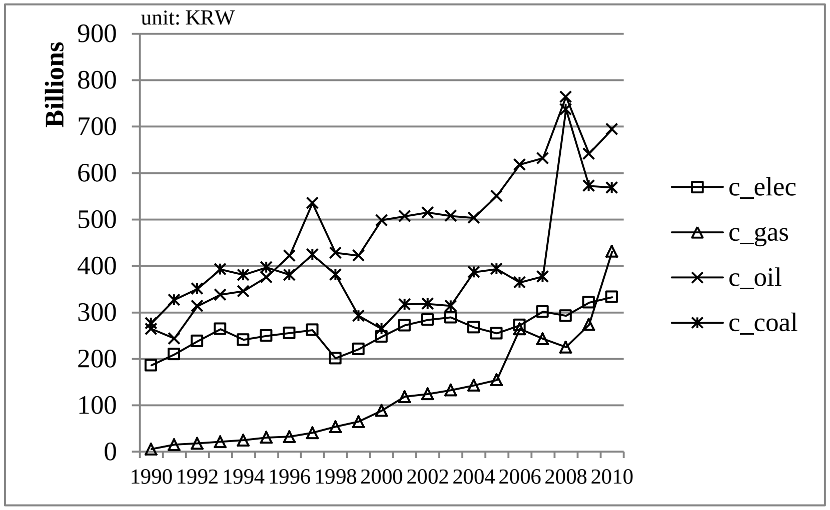

Figure 20. Cost of energy inputs for non-metal sector

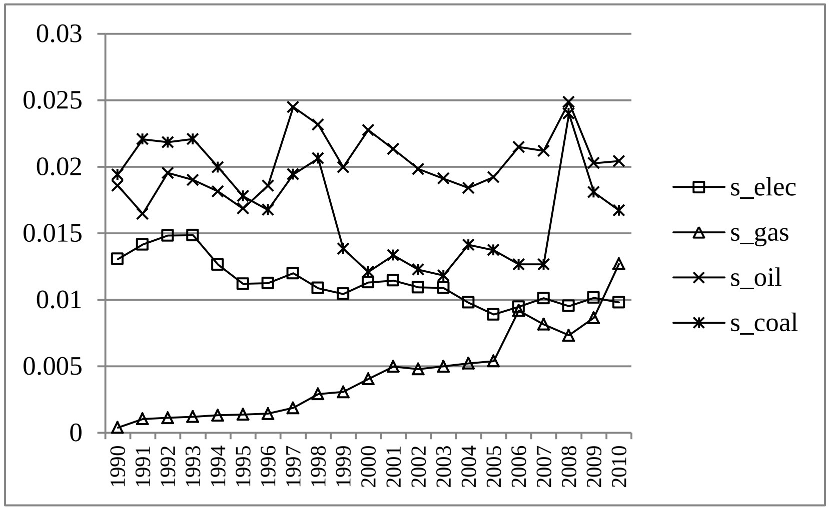

Figure 21. Cost share of energy inputs for non-metal sector

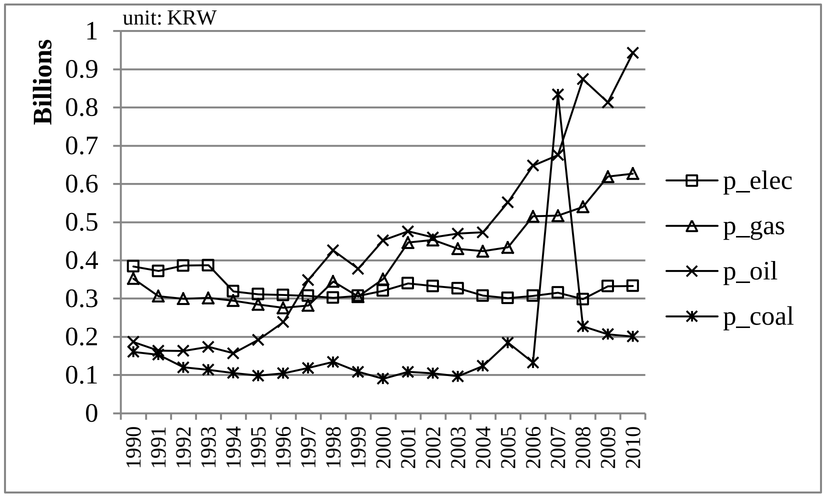

Figure 22. Price of energy inputs for iron & steel sector

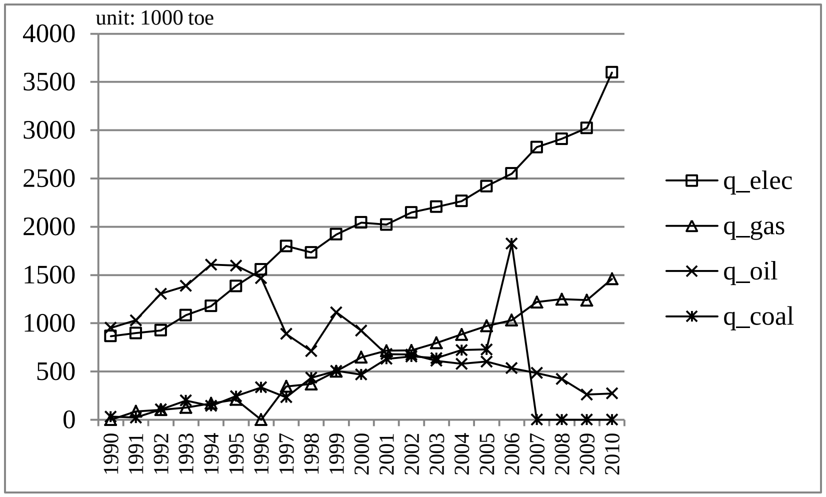

Figure 23. Quantity of energy inputs for iron & steel sector

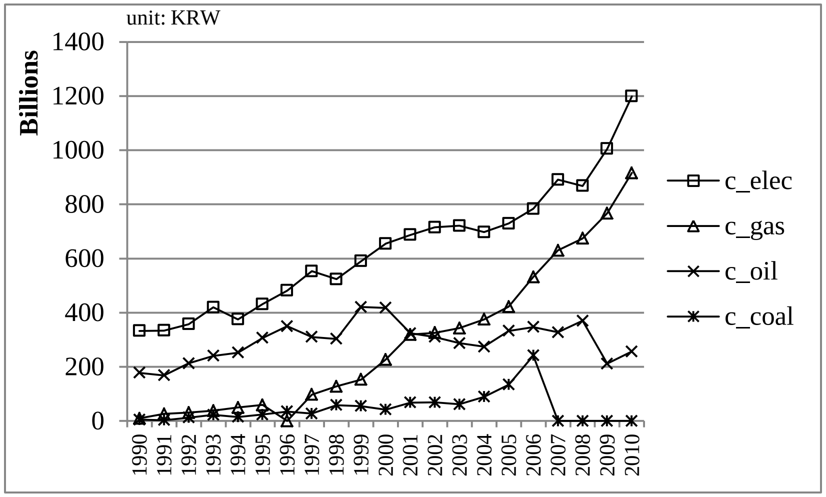

Figure 24. Cost of energy inputs for iron & steel sector

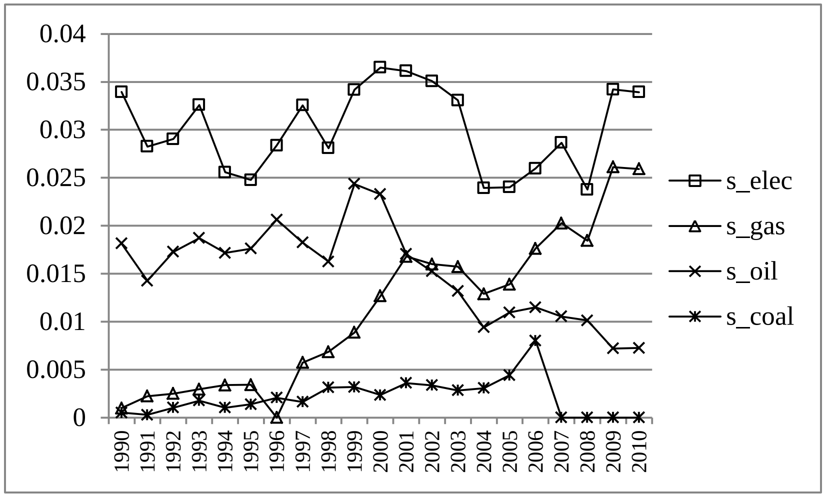

Figure 25. Cost share of energy inputs for iron & steel sector

3. RATS program

```
OPEN DATA c:\Users\Heeyoung\Desktop\Winrats\Base_Data\Man_Base_Data4.xls
cal 1990 1 1
all 2011:1
data(format=xls, org=obs)


smpl 1990:1 2011:1
set s1 = s_elec
set s2 = s_gas
set s3 = s_oil
set s4 = s_coal
set s5 = s_K
set s6 = s_L

set p1 = p_elec
set p2 = p_gas
set p3 = p_oil
set p4 = p_coal
set p5 = p_K
set p6 = p_L

set q1 = q_elec
set q2 = q_gas
set q3 = q_oil
set q4 = q_coal
set q5 = q_K
set q6 = q_L

set lnsr1 = log(s1/s6)
set lnsr2 = log(s2/s6)
set lnsr3 = log(s3/s6)
set lnsr4 = log(s4/s6)
set lnsr5 = log(s5/s6)

set lnpr12 = log(p1/p2)
set lnpr13 = log(p1/p3)
set lnpr14 = log(p1/p4)
set lnpr15 = log(p1/p5)
set lnpr16 = log(p1/p6)
set lnpr21 = log(p2/p1)
set lnpr23 = log(p2/p3)
set lnpr24 = log(p2/p4)
set lnpr25 = log(p2/p5)
set lnpr26 = log(p2/p6)
set lnpr31 = log(p3/p1)
set lnpr32 = log(p3/p2)
set lnpr34 = log(p3/p4)
set lnpr35 = log(p3/p5)
```

```
set lnpr36 = log(p3/p6)
set lnpr41 = log(p4/p1)
set lnpr42 = log(p4/p2)
set lnpr43 = log(p4/p3)
set lnpr45 = log(p4/p5)
set lnpr46 = log(p4/p6)
set lnpr51 = log(p5/p1)
set lnpr52 = log(p5/p2)
set lnpr53 = log(p5/p3)
set lnpr54 = log(p5/p4)
set lnpr56 = log(p5/p6)
set lnpr61 = log(p6/p1)
set lnpr62 = log(p6/p2)
set lnpr63 = log(p6/p3)
set lnpr64 = log(p6/p4)
set lnpr65 = log(p6/p5)
set lnqr1 = log(q1{1}/q6{1})
set lnqr2 = log(q2{1}/q6{1})
set lnqr3 = log(q3{1}/q6{1})
set lnqr4 = log(q4{1}/q6{1})
set lnqr5 = log(q5{1}/q6{1})
set delta = 0.005
set gamma = 0.05


print / lnqr1
set th12 = s2{1}/((s1{1}+delta)^gamma*(s2{1}+delta)^gamma)
set th13 = s3{1}/((s1{1}+delta)^gamma*(s3{1}+delta)^gamma)
set th14 = s4{1}/((s1{1}+delta)^gamma*(s4{1}+delta)^gamma)
set th15 = s5{1}/((s1{1}+delta)^gamma*(s5{1}+delta)^gamma)
set th16 = s6{1}/((s1{1}+delta)^gamma*(s6{1}+delta)^gamma)
set th21 = s1{1}/((s2{1}+delta)^gamma*(s1{1}+delta)^gamma)
set th23 = s3{1}/((s2{1}+delta)^gamma*(s3{1}+delta)^gamma)
set th24 = s4{1}/((s2{1}+delta)^gamma*(s4{1}+delta)^gamma)
set th25 = s5{1}/((s2{1}+delta)^gamma*(s5{1}+delta)^gamma)
set th26 = s6{1}/((s2{1}+delta)^gamma*(s6{1}+delta)^gamma)
set th31 = s1{1}/((s3{1}+delta)^gamma*(s1{1}+delta)^gamma)
set th32 = s2{1}/((s3{1}+delta)^gamma*(s2{1}+delta)^gamma)
set th34 = s4{1}/((s3{1}+delta)^gamma*(s4{1}+delta)^gamma)
set th35 = s5{1}/((s3{1}+delta)^gamma*(s5{1}+delta)^gamma)
set th36 = s6{1}/((s3{1}+delta)^gamma*(s6{1}+delta)^gamma)
set th41 = s1{1}/((s4{1}+delta)^gamma*(s1{1}+delta)^gamma)
set th42 = s2{1}/((s4{1}+delta)^gamma*(s2{1}+delta)^gamma)
set th43 = s3{1}/((s4{1}+delta)^gamma*(s3{1}+delta)^gamma)
set th45 = s5{1}/((s4{1}+delta)^gamma*(s5{1}+delta)^gamma)
set th46 = s6{1}/((s4{1}+delta)^gamma*(s6{1}+delta)^gamma)
set th51 = s1{1}/((s5{1}+delta)^gamma*(s1{1}+delta)^gamma)
set th52 = s2{1}/((s5{1}+delta)^gamma*(s2{1}+delta)^gamma)
set th53 = s3{1}/((s5{1}+delta)^gamma*(s3{1}+delta)^gamma)
set th54 = s4{1}/((s5{1}+delta)^gamma*(s4{1}+delta)^gamma)
set th56 = s6{1}/((s5{1}+delta)^gamma*(s6{1}+delta)^gamma)
```

```
set th61 = s1{1}/((s6{1}+delta)^gamma*(s1{1}+delta)^gamma)
set th62 = s2{1}/((s6{1}+delta)^gamma*(s2{1}+delta)^gamma)
set th63 = s3{1}/((s6{1}+delta)^gamma*(s3{1}+delta)^gamma)
set th64 = s4{1}/((s6{1}+delta)^gamma*(s4{1}+delta)^gamma)
set th65 = s5{1}/((s6{1}+delta)^gamma*(s5{1}+delta)^gamma)

NONLIN(parms=base) a1 a2 a3 a4 a5 a12 a15 a16 a23 a24 a25 a26 a34 a56 c1 c2 c3 c4 c5 lmd
compute a1= -2.9
compute a2= 4.4
compute a3= 6.42
compute a4= -1.9
compute a5=  -0.73
compute a12=  0.55
compute a15= 0.063
compute a16=  -0.24
compute a23=  2.73
compute a24= -0.34
compute a25= 0.201
compute a26= 0.250
compute a34= 0.281
compute a56= 0.22
compute lmd= 0.89
compute c1= 1.5
compute c2=  2
compute c3= 3
compute c4= 4
compute c5= 5
compute ha1= ha2= ha3= ha4= ha5= ha12= ha15= ha16= ha23= ha24= ha25= ha26= ha34= ha56= hc1=
hc2= hc3= hc4= hc5= hlmd= 9.0

FRML eq1 lnsr1 = a1 $
+ a12*th12*lnpr21 + a12*th13*lnpr31 + a12*th14*lnpr41 + a15*th15*lnpr51 + a16*th16*lnpr61 $
- a16*th61*lnpr16 - a26*th62*lnpr26 - a26*th63*lnpr36 - a26*th64*lnpr46 - a56*th65*lnpr56 $
+ a12*th12*(c2-c1)  + a12*th13*(c3-c1)  + a12*th14*(c4-c1)  + a15*th15*(c5-c1)  + a16*th16*(-c1) $
- a16*th61*(c1) - a26*th62*(c2) - a26*th63*(c3) - a26*th64*(c4) - a56*th65*(c5) $
+ lmd*(lnqr1)
FRML eq2 lnsr2 = a2 $
+ a12*th21*lnpr12 + a23*th23*lnpr32 + a24*th24*lnpr42 + a25*th25*lnpr52 + a26*th26*lnpr62 $
- a16*th61*lnpr16 - a26*th62*lnpr26 - a26*th36*lnpr36 - a26*th64*lnpr46 - a56*th65*lnpr56 $
+ a12*th21*(c1-c2)  + a23*th23*(c3-c2)  + a24*th24*(c4-c2)  + a25*th25*(c5-c2)  + a26*th26*(-c2) $
- a16*th61*(c1) - a26*th62*(c2) - a26*th63*(c3) - a26*th64*(c4) - a56*th65*(c5) $
+ lmd*(lnqr2)
FRML eq3 lnsr3 = a3 $
+ a12*th31*lnpr13 + a23*th32*lnpr23 + a34*th34*lnpr43 + a25*th35*lnpr53 + a26*th36*lnpr63 $
- a16*th61*lnpr16 - a26*th62*lnpr26 - a26*th63*lnpr36 - a26*th64*lnpr46 - a56*th65*lnpr56 $
+ a12*th31*(c1-c3)  + a23*th32*(c2-c3)  + a34*th34*(c4-c3)  + a25*th35*(c5-c3)  + a26*th36*(-c3) $
- a16*th61*(c1) - a26*th62*(c2) - a26*th63*(c3) - a26*th64*(c4) - a56*th65*(c5) $
+ lmd*(lnqr3)
FRML eq4 lnsr4 = a4 $
+ a12*th41*lnpr14 + a24*th42*lnpr24 + a34*th43*lnpr34 + a25*th45*lnpr54 + a26*th46*lnpr64 $
- a16*th61*lnpr16 - a26*th62*lnpr26 - a26*th63*lnpr36 - a26*th64*lnpr46 - a56*th65*lnpr56 $
```

```
+ a12*th41*(c1-c4)  + a24*th42*(c2-c4)  + a34*th43*(c3-c4)  + a25*th45*(c5-c4)  + a26*th46*(-c4) $
- a16*th61*(c1) - a26*th62*(c2) - a26*th63*(c3) - a26*th64*(c4) - a56*th65*(c5) $
+ lmd*(lnqr4)
FRML eq5 lnsr5 = a5 $
+ a15*th51*lnpr15 + a25*th52*lnpr25 + a25*th53*lnpr35 + a25*th54*lnpr45 + a56*th56*lnpr65 $
- a16*th61*lnpr16 - a26*th62*lnpr26 - a26*th63*lnpr36 - a26*th64*lnpr46 - a56*th65*lnpr56 $
+ a15*th51*(c1-c5)  + a25*th52*(c2-c5)  + a25*th53*(c3-c5)  + a25*th54*(c4-c5)  + a56*th56*(-c5) $
- a16*th61*(c1) - a26*th62*(c2) - a26*th63*(c3) - a26*th64*(c4) - a56*th65*(c5) $
+ lmd*(lnqr5)



Compute i = 1
smpl 1990:1 2011:1
loop
NLSYSTEM(parms=base, iterations=300, damp=1.0, print, sigma) / eq1 eq2 eq3 eq4 eq5

GROUP FMODEL eq1>>heq1 eq2>>heq2 eq3>>heq3 eq4>>heq4 eq5>>heq5
smpl 1990:1 2011:1
FORECAST(MODEL=FMODEL)
set ts1 = exp(heq1)/(exp(heq1)+exp(heq2)+exp(heq3)+exp(heq4)+exp(heq5)+1)
set ts2 = exp(heq2)/(exp(heq1)+exp(heq2)+exp(heq3)+exp(heq4)+exp(heq5)+1)
set ts3 = exp(heq3)/(exp(heq1)+exp(heq2)+exp(heq3)+exp(heq4)+exp(heq5)+1)
set ts4 = exp(heq4)/(exp(heq1)+exp(heq2)+exp(heq3)+exp(heq4)+exp(heq5)+1)
set ts5 = exp(heq5)/(exp(heq1)+exp(heq2)+exp(heq3)+exp(heq4)+exp(heq5)+1)
set ts6 = 1-ts1-ts2-ts3 -ts4 -ts5
set s1 = ts1
set s2 = ts2
set s3 = ts3
set s4 = ts4
set s5 = ts5
set s6 = ts6

display i
display "a1 a2 a3 a4 a5 a12 a15 a16 a23 a24 a25 a26 a34 a56 c1 c2 c3 c4 c5 lmd"
display "ha1 ha2 ha3 ha4 ha5 ha12 ha15 ha16 ha23 ha24 ha25 ha26 ha34 ha56 hc1 hc2 hc3 hc4 hc5
hlmd"
display a1 a2 a3 a4 a5 a12 a15 a16 a23 a24 a25 a26 a34 a56 c1 c2 c3 c4 c5 lmd
display ha1 ha2 ha3 ha4 ha5 ha12 ha15 ha16 ha23 ha24 ha25 ha26 ha34 ha56 hc1 hc2 hc3 hc4 hc5 hlmd
compute change = abs(ha1 - a1)
dis "change"
dis change

if abs(ha1-a1) <0.00001 .and. abs(ha2-a2) <0.00001 .and. abs(ha3- a3) <0.00001 .and. $
abs(ha4-a4) <0.00001 .and. abs(ha5- a5) <0.00001 .and. abs(ha12- a12) <0.00001 .and. $
abs(ha15- a15) <0.00001 .and. abs(ha16- a16) <0.00001 .and. abs(ha23- a23) <0.00001 .and.$
abs(ha24- a24) <0.00001 .and. abs(ha25- a25) <0.00001 .and. abs(ha26- a26)<0.00001 .and. $
abs(ha34- a34) <0.00001 .and. abs(ha56- a56) <0.00001 .and. abs(hc1- c1) <0.00001 .and.$
abs(hc2- c2)<0.00001 .and. abs(hc3- c3) <0.00001 .and. abs(hc4- c4) <0.00001 .and.$
abs(hc5- c5) <0.00001 .and. abs(hlmd- lmd) <0.00001
```

```
{dis "if#1"
NLSYSTEM(parmset=base, iterations=300, damp=1.0) / eq1 eq2 eq3 eq4 eq5
table / s_oil s_gas s_elec s_coal s_K s_L s1 s2 s3 s4 s5 s6
print / s_oil s_gas s_elec s_coal s_K s_L s1 s2 s3 s4 s5 s6
dis " converged!!! :-D <3"
dis "iteration no"
dis i
break
}
else {
dis "else#1"

compute ha1= a1
compute ha2= a2
compute ha3= a3
compute ha4= a4
compute ha5= a5
compute ha12= a12
compute ha15= a15
compute ha16= a16
compute ha23= a23
compute ha24= a24
compute ha25= a25
compute ha26= a26
compute ha34= a34
compute ha56= a56
compute hc1= c1
compute hc2= c2
compute hc3= c3
compute hc4= c4
compute hc5= c5
compute hlmd= lmd

compute i = i+1
display "i"
display i

if i>400 {
dis "if#2"
NLSYSTEM(parmset=base, iterations=300, residuals=res, damp=1.0) / eq1 eq2 eq3 eq4 eq5

table / s_oil s_gas s_elec s_coal s_K s_L s1 s2 s3 s4 s5 s6
print / s_oil s_gas s_elec s_coal s_K s_L s1 s2 s3 s4 s5 s6
dis " over iteration constraint"
break
}
end if
end loop

print / heq1 heq2 heq3 heq4 heq5 lnsr1 lnsr2 lnsr3 lnsr4 lnsr5
```

국문초록

일반 로짓모델을 이용한 국내 제조업 에너지원 가격탄력성 추정

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2013 년 8 월

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신 희 영

본 논문은 에너지를 중심으로 제조업의 생산 투입 요소의 자기가격탄력성과 교차가격탄력성을 추정해본다. 일반 로짓모델을 사용하고, 생산 요소로 전기, 석유, 가스, 석탄, 노동, 자본을 고려한다. 우선 제조업 전체에 대해서 모형을 적용한 후, 이를 제조업 내 세부 분류인 석유화학, 비금속, 철강 세 개의 업종에 추가적으로 적용해본다. 그 과정에서 일반 로짓모델에 비중 상수를 적용함으로써 실측 자료를 가장 잘 설명할 수 있는 함수 형태를 도출한다. 일반 로짓모델로부터 추정한 가격탄력성이 과거 트렌드를 설명하기에 적합한 지표이지만, 모델에서 사용하는 비중 상수에 따라 도출되는 가격탄력성의 크기가 다르기 때문에 미래의 에너지 가격 변동에 의한 수요의 변화에 대해서는 정확한 결론을 내릴 수 없다. 일반 로짓모델을 적용했을 때 비중 상수와 무관하게 도출할 수 있는 결론에 한해서만 정책적 함의를 논할 수 있고, 향후 후속 연구들 또한 일반 로짓모델을 사용할 때에는 비중 상수에 대하여 별도의 격자탐색법을 수행해야 한다.

◆ 주요어 : 가격탄력성, 일반로짓모델, 생산함수, 에너지 투입요소, 제조업

◆ 학 번 : 2011-23928